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International Workshop on Innovation of Developing the Strategy for Impact Assessment of and Adaptation to the Climate Change as the “New Normal” (CLIMATE)
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INTEGRATED ASSESSMENT OF CLIMATE CHANGE IMPACTS ON SELECTIVE FARMING SYSTEMS IN SOUTH AFRICA

Oosthuizen, H.J.¹ and Louw, D.B.²

ABSTRACT

In order to determine possible impacts of projected future climates on the financial vulnerability of selective farming systems in South Africa, a case study methodology was applied. The integrated modelling framework consists of four modules, viz.: climate change impact modelling, dynamic linear programming (DLP) modelling, modelling interphases and financial vulnerability assessment modelling. Empirically downscaled climate data from five global climate models (GCMs) served as base for the integrated modelling. The APSIM (Agricultural Production Systems sIMulator) crop model was applied to determine the impact of projected climates on crop yield for certain crops in the study. In order to determine the impact of projected climates on crops for which there are no crop models available, a unique modelling technique, Critical Crop Climate Threshold (CCCT) modelling, was developed and applied to model the impact of projected climate change on yield and quality of agricultural produce. Climate change impact modelling also takes into account the projected changes in irrigation water availability (ACRU hydrological model) and crop irrigation requirements (SAPWAT3 model) as a result of projected climate change. The model produces a set of valuable results, viz. projected changes in crop yield and quality, projected changes in availability of irrigation water, projected changes in crop irrigation needs, optimal combination of farming activities to maximize net cash flow, and a set of financial criteria to determine economic viability and financial feasibility of the farming system. A set of financial criteria; i.e. internal rate of return (IRR), net present value (NPV), cash flow ratio, highest debt ratio, and highest debt have been employed to measure the impact of climate change on the financial vulnerability of farming systems. Adaptation strategies to lessen the impact of climate change were identified for each case study through expert group discussions.

Keywords: Adaptation strategies, Integrated climate change modelling, Crop water requirement changes, South Africa.

1. INTRODUCTION

It is critical to determine the possible impacts and consequences of projected future climates on the financial vulnerability of different farming systems and to evaluate suggested adaptation strategies. The methodology integrates a number of models viz. empirically downscaled General Circulation Models (GCMs), hydrological, crop yield and quality models, Dynamic Linear Programming (DLP) and Financial Vulnerability Assessment models to accurately assess the impact of projected future climates on the financial vulnerability of different farming systems.

Farmers have developed various strategies to cope with the current climate variability experienced in South Africa. These strategies, however, may not be sufficient to cope with projected future climatic changes which could potentially increase the financial vulnerability of farming systems significantly. The identification of new adaptation strategies and in some instances the re-thinking of existing strategies to reduce...
financial vulnerability is of paramount importance for future sustainability of the agricultural sector in South Africa (Oosthuizen, 2014). Because of the complexity of South Africa’s physiography, climate and socio-economic milieu, detailed local scale analyses are needed to assess potential impacts (Schulze, 2011).

2. METHODS

2.1 Case Study Approach

A case study methodology was applied instead of considering representative farms for the selected study areas. The benefit of considering specific farms on a case study level is that a much more detailed analysis can be performed. The participating case study farmers were selected in conjunction with local role-players.

The research covers four selected case study areas. These case study areas are based on typical farming systems in the following districts:

- Vredendal, Western Cape Province (LORWUA): Irrigation - winter rainfall region.
- Moorreesburg, Western Cape Province: Dryland - winter rainfall region.
- Hoedspruit, Limpopo Province (Blyde River WUA): Irrigation - summer rainfall region.
- Carolina, Mpumalanga Province: Dryland - summer rainfall region.

2.2 Climate Change Impact Modelling

In order to analyse the financial vulnerability of the selected case studies to climate change, an integrated climate change model was developed. The modelling framework consists of four modules. These are:

- Climate change impact modelling:
- Modelling of physical climate data (daily minimum and maximum temperatures and daily rainfall from different downscaled GCMs) that impact on crop yield and quality through APSIM and CCCT modelling.
- Hydrological modelling (ACRU model) - impact of climate change on the availability of irrigation water (for the Blyde River WUA).
- Changing crop irrigation requirements (as a result of climate change) through SAPWAT3 model.
- Dynamic Linear Programming model.
- Modelling interphases.
- Financial Vulnerability Assessment model.

Condensed description of models applied in the study

General Circulation models (GCMs)

The climate change scenarios developed by the Climate Systems Analysis Group (CSAG) for application in this project were derived from global scenarios produced by five GCMs, all of which were applied in the IPCC’s (2007) Fourth Assessment Report [AR4] (Schulze et al., 2011). The GCMs are: CCC (Canada), CRM (France), ECH (Germany), GISS (USA) and IPS (France). All of the future global climate scenarios that were downscaled by CSAG to point scale for use in this study were based on the A2 emissions scenario (Figure 4.2) defined by the IPCC SRES (Nakićenović et al., 2000).
APSIM (crop yield modelling)

APSIM was developed to simulate biophysical processes in agricultural systems, particularly as it relates to the economic and ecological outcomes of management practices in the face of climate risk. It is structured around plant, soil and management modules. These modules include a diverse range of crops, pastures and trees, soil processes including water balance, N and P transformations, soil pH, erosion and a full range of management controls. APSIM resulted from a need for tools that provided accurate predictions of crop production in relation to climate, genotype, soil and management factors while addressing the long-term resource management issues (Keating et al., 2003).

CCCT (crop yield and quality modelling)

The CCCT modelling technique is based on the following pillars:

- Empirically downscaled daily climate values (rainfall, minimum and maximum temperatures).
- Physical/biological critical climate thresholds for different crops.
- Expert group discussions (for guidance on crop critical climate thresholds and also the impact on yield and/or quality should a threshold be exceeded).

The use of expert group discussions, as a research method is suitable, firstly, for gathering information in a meaningful manner and, secondly, to stimulate individual creativity by presenting alternative perspectives provided by various participating experts (Hoffmann, 2010). However, due to the various uncertainties in the models, when analysing CCCT modelling results the emphasis should be on trends in projected yield and quality, rather than absolute values.

ACRU (hydrological modelling)

The projected future dam levels for the Blydepoort Dam were computed by the Centre of Water Resources Research in the School of Agricultural, Earth and Environmental Science, University of KwaZulu-Natal (UKZN). The daily present and intermediate climate values from downscaled GCMs were used in the ACRU model to project future changes in dam levels.

SAPWAT3 (crop water requirement modelling)

SAPWAT3 is essentially an enhanced and improved version of SAPWAT (South African Plant WATer), a program that is extensively applied in South Africa and was developed to establish a decision-making procedure for the estimation of crop irrigation requirements by irrigation engineers, planners and agriculturalists (Van Heerden et al., 2009).

Whole-farm dynamic linear programming approach

The main objective of the mathematical modelling exercise is to simulate the selected farming systems (case studies) with the best available information. Climate change scenario data are then imported into the models to study the impact on economic and financial vulnerability with no adaptation. In the second round of analysis adaptation strategies are tested to analyse their efficiency in reducing vulnerability.
Modelling interphases

The development of interphases between the downscaled climate data sets which were applied in the CCCT, ACRU and SAPWAT3 models and the DLP model is of paramount importance. Not only do they enable a better understanding of the relative changes in the observed and projected climate, but they also make a substantial contribution towards the interpretation and the dissemination of the results. For the purpose of this project, four interphases were developed. They are:

- The APSIM crop yield model – DLP model interphase
- The CCCT yield and quality model – DLP model interphase
- The ACRU hydrological model - DLP model interphase
- The SAPWAT3 crop irrigation requirement – DLP model interphase
- An interphase to generate at random variation coefficients to be imposed on all the crops in the model where APSIM/CCCT models are not available.

Financial Vulnerability Assessment model

The output of the DLP whole-farm model feeds into an excel-based financial assessment model. In order to determine the financial vulnerability of the farming system, a set of criteria provided for in the financial model are applied.

These criteria are:

- Internal Rate of Return (IRR)
- Net Present Value (NPV)
- Cash flow ratio
- Highest debt ratio
- Highest debt

The financial vulnerability assessment in respect of each case study includes individual assessment runs for present and intermediate climate scenarios for each of the five GCMs included in the study.

2.3 Adaptation Strategies

Within the context of this study the focus will be on autonomous adaptation, in other words, adaptation strategies which can be applied at farm level without support from other levels e.g. policies, etc.

Adaptation strategies to lessen the impact of climate change were identified for each case study through expert group discussions.

Adaptation strategies along with their cost/benefit implications were incorporated in the model to evaluate their suitability and ability to overcome the potential negative financial impacts as a result of changing climates.

2.4 Data Used

In order to construct a mathematical programming model which accurately represents the impact of climate change on the financial vulnerability of the selected case studies, both primary and secondary data are required. These data requirements are:

- Primary data of selected case study farms.
- Crop enterprise budgets data.
• Point-scale daily climate data (temperature and rainfall) for current and future projected climates.
• Hydrological data to determine availability of irrigation water (current and future) and crop irrigation requirements (current and future).
• APSIM crop modelling data (current and future).
• CCCT model data for crops where no crop models exist.
• Possible adaptation strategies and alternative crops.

3. RESULTS AND DISCUSSION

3.1 (LORWUA) – Irrigation, Winter Rainfall Region

The modelling results for the LORWUA case studies can be summarised as follows:

• Climate data from four GCMs was applied in the APSIM modelling. All the GCMs project a 20-year average decrease in yield, varying from 9% to 18%.
• Data from five GCMs was applied in the CCCT model. All five models project a decrease in yield for wine grapes, table grapes and raisins and a decrease in quality for table grapes.
• A 10% average annual increase in irrigation requirements is projected for table grapes for intermediate future climates in order to obtain the same yield as with present climates. For wine grapes and raisins, an 11% average increase in irrigation requirements is projected.
• The ACRU was not included in the integrated climate change modelling for LORWUA due to unvalidated data sets.
• Both climate change financial modelling techniques (APSIM crop modelling and CCCT modelling technique) indicate that intermediate climate scenarios from five different GCMs pose a threat to the financial vulnerability of farming systems in the LORWUA grape producing area.
• Several adaptation strategies to counter the impact of climate change on financial vulnerability were included in the model. These strategies include:
  • Shift wine grape cultivars towards cultivars that are more tolerant towards projected climate change
  • Increase raisin and table grape production
  • Install shade nets over table grapes production areas.
• The above adaptation strategies all seem to lessen the impact of climate change on financial vulnerability to a certain extent and seem worth further investigation.
• Adaptation strategies not included in the model, but worth investigation, include:
  • Irrigation at night to save water
  • Plastic or mulch cover to conserve moisture
  • Soil preparation and site selection for future plantings in order to ensure optimum production – rather scale down and eliminate marginal blocks.

3.2 (Blyde River WUA) – Irrigation, Summer Rainfall

The modelling results for Blyde River WUA case studies can be summarised as follows:

• Empirically downscaled climate values of five GCMs were applied in the CCCT model. Although, only one out of five GCMs projects a decrease in yield for
citrus, all models project a negative impact on quality. For mangoes the models project a negative impact on both yield and quality. Only mangoes and citrus were simulated for the Blyde River WUA.

- An 8% average annual increase in irrigation requirements is projected for both citrus and mangoes for intermediate future climates in order to obtain the same yield as with present climates.

- The projection of the Blydepoort Dam level was done by UKZN, using the ACRU model. All indications are that the availability of irrigation water for the Blyde River WUA area irrigators (in terms of quota consistency) will not be negatively affected by the projected climate scenarios.

- The CCCT modelling results indicate that intermediate climate scenarios from different GCMs pose a threat to the financial vulnerability of farming systems in the Blyde River mango and citrus producing area.

- The impact of intermediate climate scenarios on financial vulnerability will be more severe on farming systems that are highly geared (high debt levels).

- An adaptation strategy to counter the impact of climate change on financial vulnerability is to install shade nets over mango and citrus production areas. The installation of shade nets proves to lessen the impact of climate change on financial vulnerability to a certain extent and seems worthwhile to investigate further.

- Adaptation strategies not included in the model, but worth investigation, include:
  - Mulching cover to conserve moisture
  - More effective management of irrigation systems
  - Cultivar development to increase natural heat resistance.

### 3.3 Moorreesburg, Western Cape Province – Dryland, Winter Rainfall Region

The modelling results for the Moorreesburg case study can be summarised as follows:

- Climate data from four GCMs were applied in the APSIM modelling to project intermediate future yield for wheat. The different GCM projections (20-year average) vary from a decrease of 4% to an increase of 4% compared to present yield. The overall average yield between the four models equals the average present yield. Wheat was the only crop simulated for the Moorreesburg case study.

- Data from five GCMs was used in CCCT modelling. Despite relatively small variances between the different GCM projections, no major changes in yield, from the present to the intermediate future, are projected. This result correlates with the APSIM crop modelling results, which increases confidence in the CCCT modelling technique.

- Both climate change financial modelling techniques (APSIM crop modelling and CCCT modelling technique) indicate that intermediate climate scenarios from different GCMs pose a very marginal threat to the financial vulnerability of farming systems in the Moorreesburg dryland wheat producing area.

- The impact of intermediate climate scenarios on financial vulnerability will be more severe on farming systems that are highly geared (high debt levels).

- Adaptation strategies to counter the impact of climate change on financial vulnerability were included in the model. These strategies include:
3.4 Carolina, Mpumalanga Province – Dryland, Summer Rainfall Region

The modelling results for the Carolina case study can be summarised as follows:

- Climate data from four GCMs was applied in the APSIM modelling to project intermediate future yield for maize. One model projects an average decrease of 25% while three models project an increase in average yield of approximately 10%.
- Data from five GCMs was used in CCCT modelling. All five models project an average increase in yield of approximately 10%. This result correlates to a large extent with the APSIM crop modelling results where three out of four models projected similar increases in average yield.
- Both climate change financial modelling techniques (APSIM crop modelling and the CCCT modelling technique) indicate that intermediate climate scenarios from five different GCMs pose no threat to the financial vulnerability of farming systems in the Carolina summer rainfall dryland area. Please note that abnormal climate events like storms, hail, etc., are not included in the climate modelling.
- Adaptation strategies to counter the impact of climate change on financial vulnerability were included in the model. These strategies include:
  - Cropping systems
  - Production practices.
- The above adaptation strategies seem not only to counter the impact of climate change, but to positively impact on profitability.

4. CONCLUSIONS

This study clearly indicates the importance of biophysical factors and the capacity to adapt to climate change. The Moorreesburg as well as the Carolina case study results indicated that changing to conservation agriculture (more resilient cropping system) improves the adaptive capacity of the farming systems. In the Blyde River WUA case study, shade netting improves the biophysical adaptive capacity of mangoes and citrus (in terms of yield and quality). The LORWUA case study showed similar results for table grapes under shade nets.

For the Carolina case study, all five CCCT models project an average increase in maize yield of approximately 10%. This result correlates to a large extent with the APSIM crop modelling results where three out of four models projected similar increases in average yield and the findings of Du Toit et al. (2002). The study results show that, similar to Nelson et al. (2009), some regions will gain due to the impact of climate change and some will lose e.g. Blyde River WUA area (mangoes and citrus). The results of the study echoed those of Andersson et al. (2009), indicating that impacts of a changing climate could be considerable. Different regions of the country will likely be affected in many different ways. For this reason alone local scale analyses are needed to assess potential impacts (showing the importance of a micro scale integrated climate change modelling approach).
As already been pointed out by various studies, this study also clearly illustrates that, without the capacity to implement adaption strategies such as conservation agriculture (Moorreesburg and Carolina), shade netting (LORWUA and Blyde River WUA) and structural changes to land use patterns (LORWUA), the farming systems of the selected case studies will financially be extremely vulnerable to climate change (as indicated by reduction in IRR and NPV, higher debt ratios and decreasing cash flow ratios).

The high capital cost of certain adaptive strategies, e.g. shade nets would not be affordable to all farmers, especially on smaller operations and those that are highly geared. Systematic and timely implementation over a longer period of time can reduce the pressure on cash flow. This once again highlights the importance of strategic and long term planning, in which Government also could have a role to play. Timely research efforts should be implemented to determine the most appropriate adaptation strategies and communicate research findings on an ongoing basis to all role-players. For the sake of food security, regional socio-economic welfare, protection of much needed export earnings and to preserve land resources for generations to come, it may be worthwhile to investigate subsidies or green box grants in some instances to assist farmers to timeously adapt to projected climate change.

The Scottish Government, for instance, has developed a policy initiative, "Farming for a better climate (FFBC)", with the specific aim of mitigating climate change in agriculture. The FFBC has a communication programme that encourages farmers to adopt efficiency measures that reduce emissions, while at the same time having an overall positive impact on business performance. The purpose of such a body could not only be to identify and research the best practices, etc. but also to serve as communication channel to inform and keep role-players up to date with latest research, developments, etc.

This study shows the importance of research for cultivar development e.g. short grower cultivars (e.g. maize) for the summer rainfall area and more heat resistant cultivars for the Blyde River WUA area (citrus and mangoes). It also points out the importance of locality for future plantings and the projected switch to cultivars that are more tolerant to increasing temperatures (e.g. wine grape cultivars in the LORWUA area). The different results in terms of yield and quality projections for the four case study areas emphasise the importance of locality specific climate change research. In the summer rainfall area, for example, an increase in yield is projected for maize (Carolina case study) compared to a projected decrease in yield and quality for citrus and mangoes (Blyde River WUA area). The impact of projected climate change on yield and quality also differs in the winter rainfall area; the LORWUA grape producing area seems more vulnerable than the dryland wheat producing area of Moorreesburg.

In terms of vulnerability, the sensitivity in Moorreesburg is relatively low compared to e.g. the Blyde River WUA farming systems where adaptation strategies (shade nets) are more costly than adaptation strategies in Moorreesburg (converting to conservation agriculture and alternative cropping systems). The return on investment for implementing adaptation strategies is also more rapid for Moorreesburg compared to the Blyde River WUA area.

This study points out that citrus and mangoes in the Blyde River WUA area are extremely vulnerable to increasing temperatures. This is because prices of perishable produce depend to a large extent on quality grading and market requirements. The Moorreesburg and Carolina dryland mixed crop and livestock farming systems are less vulnerable.
5. REFERENCES


ASSESSMENT OF CLIMATE CHANGE IMPACTS USING HYDROLOGICAL DROUGHT INDEX

Levina¹, Brigita Diaz² and Waluyo Hatmoko³

ABSTRACT

Climate change is altering the characteristics of rainfall and consequently also the river flow. It is important to assess climate change impact on drought, especially hydrological drought in river flow. This paper proposes to quantify climate change impact using hydrological drought index, from the available flow data. Climate change impact on rainfall in the future is projected using the worst scenario Representative Concentration Pathways (RCP) 8.5 that leading in the long term to high energy demand and greenhouse gas emissions in the absence of climate change policies, as mentioned in the latest IPCC report AR 5. The monthly rainfall is projected until the year of 2045 using ensemble of seven models commonly used by Indonesian Agency for Meteorology, Climatology and Geophysics which is statistical-bias corrected by quantile mapping with observation data. Projected river discharge is calculated using an empirical equation between changes in discharge with potential evaporation and rainfall. A set of hydrological drought index are computed using the Standardized Runoff Index (SRI) method with moving average of 1, 3, 6, and 12 months. Case study of the three irrigation weirs Bodri-Juwero, Notog, and Wlingi in Java confirms that hydrological drought index can be applied to assess the climate change impact in surface water especially at irrigation weirs. It is concluded that the severity and stress of hydrological drought index follow the same pattern of climate change impact on irrigation area affected by drought. The projected hydrological drought index for the next 30 years shows increasing of drought severity with longer drought duration at irrigation weirs.

Keywords: climate change, drought, hydrological drought, drought index, irrigation, irrigation weir

1. INTRODUCTION

Hydrological system is highly affected by climate change. Water availability characteristics in the future will change substantially. Dry season with decreasing low flow will be in longer duration. In other word, the drought will be more severe, and the duration of the drought will be longer. Drought is a creeping disaster, originate from lack of rainfall or meteorological drought, which cause decreasing flows in the rivers and drawdown of lakes, and becoming hydrological drought. Hydrological drought index is having higher correlation with the irrigation are affected by drought than meteorological drought. Climate change impact assessment using hydrological drought index at the irrigation weir have the advantage of directly related to irrigation drought. This paper proposes to quantify climate change impact using hydrological drought index, which is simple to measure and highly related with drought. Please explain why the case study sites are selected. This concept is validated using irrigation weirs having good long time-series of monthly river flow data as well as the pairing hectares of irrigation areal affected by drought.

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2. METHODS

2.1 Case Study: Irrigation Weir Notog, Kragilan and Wlingi

Bodri Juwero river gauging station is in the Bodri river right on Juwero weir, Central Java Province. Juwero weir is supplying the irrigation area with an area of 8,861 ha which covers Kendal Regency, Central Java. Notog river gauging station was at the Notog weir of the Pemali river. Notog weir irrigates an irrigation area of 15,180 ha which covers Brebes Regency, Tegal Regency, and Tegal City, Central Java Province. Different from Bodri-Juwero and Notog river gauging station which located in the Central Java region, Wlingi river gauging station is located in East Java around the Wingi Dam. The Wingi Dam is an intake from Lodoyo irrigation area with an area of 15,228 ha covering the areas of Blitar and Tulungagung Regencies. The location of the three irrigation weirs are in Figure 1.

![Location of Bodri-Juwero, Notog, and Wlingi Irrigation Weirs](image)

Source: Ministry of Agriculture Indonesia (2018)

2.2 Climate Change Projections and Datasets

Climate change impact on rainfall in the future is projected using the worst scenario Representative Concentration Pathways (RCP) 8.5 that assumes high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and greenhouse gas emissions in the absence of climate change policies, as mentioned in the latest IPCC report AR 5. The monthly rainfall is projected until the year of 2045 using ensemble of seven models commonly used by Indonesian Agency for Meteorology, Climatology and Geophysics, those are CNRM CM5, CNRM RCA, CNRM v2 RegCM, CSIRO MK3,6, EC EARTH, GFDL ESM, and IPSL.

Data were divided into two groups consists of baseline periods (1981-2005) and projection period (2006-2045). Projection rainfall data is bias-corrected by using statistical bias corrected methods, quantile mapping. We use CHIRPS dataset as observation rainfall data. CHIRPS data has high resolution and long data sequences so able to cover blank areas, disconnected data, and data inconsistencies in Indonesia area (Sutikno et al (2014) in Fadholi & Adzani, 2018)).

To project discharge, empirical projection method is used with observation rainfall and potential evaporation obtained from Potential Evaporation Climatic Research Unit Time Series (CRU TS) version 4.01 (University of East Anglia, n.d.). The empirical
methods assumed that changes in discharge for each month are caused by changes in monthly rainfall and potential evaporation. Empirical methods steps to make the discharge projection is further explained in Risbey & Entekhabi (1996) and Fu, Charles, & Chiew (2007). In the projection period, year of 2006-2015 is used as the control period to compare the results of discharge projections with gauging station observational data. Furthermore, for the SRI calculation, we use projected models from seven models and the average of the seven models.

2.3 Hydrological Drought Index

Based on the seven projected discharge models, a set of hydrological drought index are computed using the Standardized Runoff Index (SRI) method with moving average of 1, 3, 6, and 12 months. This method applies the concept employed by McKee et al. (1993) for the SPI in defining a standardized runoff index (SRI) as the unit standard normal deviation associated with the percentile of hydrologic runoff accumulated over a specific duration (Shukla and Wood, 2008).

The procedure for calculating the SRI includes the following steps: (1) A retrospective time series of runoff is obtained by simulation, and a probability distribution is fit to the sample represented by the time series values. (2) The distribution is used to estimate the cumulative probability of the runoff value of interest (either the current accumulation or one from a retrospective date). (3) The cumulative probability is converted to a standard normal deviation (with zero mean and unit variance), which can either be calculated from a numerical approximation to the normal cumulative distribution function (CDF) or extracted from a table of values for the normal CDF that is already available in statistics text books or on the World Wide Web (Shukla and Wood, 2008).

3. RESULTS AND DISCUSSION

3.1 Climate Change Projections

As shown in Figure 1, at high discharge level the seven models give overestimate value with the discharge measured by gauging. The difference between projection with observation is especially shown at the high discharge at Wlingi Weir. As with the probability value of 10%, the average value of the seven models reaches 300 m$^3$/s, while the observation value only ranges from 190 m$^3$/s. At Juwero Weir there is also a significant difference between the calculated discharge and what happens in the field where the probability value of 10% the discharge projection is at the value of 70.4 m$^3$/s while the observation discharge value is 51.65 m$^3$/s. But at Notog Weir from the seven models there are several models that can provide results that are closer to the discharge observation value at high discharge values, such as the EARTH EC model and GFDL ESM.

While at the low discharge value, the projection discharge can give better results with the observation discharge value of each station gauging. At Q50% value the value tends to be very close (Wlingi Gauging Station discharge average 110.86 m$^3$/s, observation 108.75 m$^3$/s, Juwero Gauging Station discharge average 21.49 m$^3$/s, observation 22.24 m$^3$/s, and Notog Gauging Station discharge average 52.36 m$^3$/s, observation 52.21 m$^3$/s). Whereas the Q80% discharge projection tends to underestimate two stations and overestimate one station (Wlingi Gauging Station discharge average 42.08 m$^3$/s, observation 62.17 m$^3$/s, Juwero Gauging Station average discharge 7.57 m$^3$/s, observation 11.14 m$^3$/s, and the average Notog Gauging Station discharge is 19.60 m$^3$/s, observation is 16.52 m$^3$/s). But in general, the projection debit of the seven models can provide good results on the average discharge value to low discharge.
Due to the fact that the projections give better results in Q50% value, then for comparing value between 2006-2015, 2026-2035, and 2036-2045 average value Q50% will be applied.

**Figure 2. Projection and Observation Flow Duration Curve in 2006-2015**

In 2026-2035 at Wlingi Gauging Station four models shows decreased Q50% discharge value varies from -5% to -37%, Juwero Gauging station six models will decrease from -5% to -31%, and Notog Gauging Station four models a slight increased +0.3% to 12%. Furthermore in 2036-2045 period five models at Wlingi Gauging Station shows decreased discharge from -2% to -38%, four models at Juwero Gauging Station four models decreased from -4% to -55%, and Notog Gauging Station four models decreased -1% to 55%. It can be concluded mostly that discharge at Wlingi Gauging Station, Juwero Gauging Station, and Notog Gauging Station would be decreased in 2026-2035 and 2036-2045, except at Notog Gauging Station in 2026-2035 compared to present condition.

3.2 Hydrological Drought Index

Case study of the three irrigation weirs (Bodri-Juwero, Notog, and Wlingi) in Java is to demonstrate that hydrological drought index can be applied to assess the climate change impact in surface water especially drought at irrigation weirs. The calculation of the hydrological drought index using the SRI method is carried out on 1, 3, 6, 9, and 12 months’ time scales by using observed monthly discharge data from river gauging stations at each irrigation weirs.
Table 1. Q50% Projected Monthly Discharge

<table>
<thead>
<tr>
<th>Irrigation Weir</th>
<th>Period</th>
<th>CNRM CM5</th>
<th>CNRM RCA</th>
<th>CNRM v2 RegCM</th>
<th>CSIRO Mk3.6</th>
<th>EC EARTH</th>
<th>GFDL ESM</th>
<th>IPSL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wlingi</td>
<td>2006-2015</td>
<td>129.95</td>
<td>105.66</td>
<td>133.63</td>
<td>82.65</td>
<td>71.95</td>
<td>96.03</td>
<td>156.17</td>
</tr>
<tr>
<td></td>
<td>2026-2035</td>
<td>122.92</td>
<td>97.45</td>
<td>121.53</td>
<td>89.78</td>
<td>76.07</td>
<td>122.98</td>
<td>98.99</td>
</tr>
<tr>
<td></td>
<td>2036-2045</td>
<td>121.91</td>
<td>103.66</td>
<td>99.17</td>
<td>106.18</td>
<td>93.75</td>
<td>59.69</td>
<td>128.55</td>
</tr>
<tr>
<td></td>
<td>2026-2035</td>
<td>26.61</td>
<td>20.48</td>
<td>26.44</td>
<td>22.89</td>
<td>13.72</td>
<td>21.76</td>
<td>17.01</td>
</tr>
<tr>
<td></td>
<td>2036-2045</td>
<td>18.94</td>
<td>22.45</td>
<td>19.80</td>
<td>23.49</td>
<td>16.97</td>
<td>10.42</td>
<td>20.70</td>
</tr>
<tr>
<td>Notog</td>
<td>2006-2015</td>
<td>53.93</td>
<td>51.64</td>
<td>56.26</td>
<td>53.92</td>
<td>40.99</td>
<td>49.96</td>
<td>59.83</td>
</tr>
<tr>
<td></td>
<td>2026-2035</td>
<td>59.32</td>
<td>57.69</td>
<td>56.76</td>
<td>54.10</td>
<td>40.55</td>
<td>52.90</td>
<td>56.74</td>
</tr>
<tr>
<td></td>
<td>2036-2045</td>
<td>51.18</td>
<td>54.20</td>
<td>48.76</td>
<td>53.46</td>
<td>48.40</td>
<td>22.26</td>
<td>61.66</td>
</tr>
</tbody>
</table>

Figure 3. The SRI Values on Various Time Scales at Bodri-Juwero River Gauging Station

Figure 3 shows the severity of hydrological drought at Bodri Weir, which is stable in the near normal to severely dry all time scale within a period of 20 years (1981-2002), but from 2003-2008 the severity of drought in the Bodri Weir increased sharply to an extreme dry level, and in that period Bodri irrigation area is suffering a water crisis.

For Notog weir which covering Notog irrigation areas (Figure 4a), in the period 1991-2013 almost all SRI (except SRI-1) showed the severity of drought was in normal conditions.

Whereas of the Lodoyo irrigation area with the intake from Wlingi Dam (Figure 4b), the average severity of drought is in a normal condition to severely drought. Only in 1997-1998 and 2007 were in extreme dry conditions. The condition of the severity of the drought applies to all SRI time scales.

3.3 Correlation between Hydrological Drought and Climate Change Impact

The relation between hydrological drought index and the impact of drought is represented using a correlation coefficient between the severity, duration and stress the drought versus areal affected by drought. Drought stress is the multiplication product between drought severity and drought duration. The rice field affected by drought was obtained from the Ministry of Agriculture with data period from 1997 to 2012. The results of the correlation coefficient are presented in Figure 5 and Table 2.
Figure 4. The SRI Values on Various Time Scales at Notog (a) and Wlingi (b) Weirs

From the Table 2, in the Bodri-Juwero irrigation weir shows that there is a strong correlation between drought stress and the hectares of rice fields affected by drought, which is SRI-12, while for the Notog irrigation weir which gives a strong correlation, is SRI 1.

In Wlingi area, the “best correlation” of drought intensity to the acres of paddy fields affected occurred in SRI-12, while for the best correlation in stress is SRI-3. In other word, the highest correlation of hydrological drought index (SRI) time scale to the rice fields affected drought means the better index in expressing he impact of hydrological drought

These drought analysis at present control period, suggest the possibility to predict the impact of climate change scenarios in the next few decades for the Bodri Juwero irrigation weir focusing on SRI 12, Notog on SRI 1, and for the Wlingi irrigation weir focus on SRI 3. Predicted SRI projections are calculated using GCM RCP 8.5 projection on monthly discharge data from the average and minimum value of the seven GCM models.

Figure 5. Comparison SRI Annual Drought Stress in The Bodri-Juwero (a), Notog (b), and Wlingi Irrigation Weir (c) to number of hectares of rice fields affected by drought
Table 2. Correlation between drought stress and the number of hectares of rice fields affected by drought for different time-scale of SRI

<table>
<thead>
<tr>
<th>SRI</th>
<th>Bodri-Juwero</th>
<th>Notog</th>
<th>Wlingi</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27.3%</td>
<td>70.8%</td>
<td>48.8%</td>
</tr>
<tr>
<td>3</td>
<td>29.3%</td>
<td>61.1%</td>
<td>52.9%</td>
</tr>
<tr>
<td>6</td>
<td>30.8%</td>
<td>49.4%</td>
<td>49.5%</td>
</tr>
<tr>
<td>9</td>
<td>33.3%</td>
<td>36.4%</td>
<td>47.8%</td>
</tr>
<tr>
<td>12</td>
<td>33.8%</td>
<td>32.0%</td>
<td>40.0%</td>
</tr>
</tbody>
</table>

Figure 6. SRI-12 Projection in Bodri-Juwero

Figure 7. SRI-1 Projection in Notog (a) and SRI-3 Projection in Wlingi (b)
In Bodri-Juwero irrigation area in the next 20 years ahead, it is indicated that the extreme drought with duration of 2 years will occur twice, on the year of 2022 – 2023, and on the year of 2041 – 2043 (Figure 6).

Based on Figure 7a, in the next 20 years the extreme drought of Notog irrigation weir will occur more frequently compared to the historical drought as presented in Figure 4a, where the extreme drought in the historical drought only occurred at the El-Nino event.

In the Wlingi irrigation weir (Fig. 7b), hydrological drought is predicted to occur in almost all of the decades, and extreme drought might at all drought time scale in some years, a similar hydrological drought pattern as predicted in Bodri-Juwero. Unlike present situation of relatively rare and mild hydrological drought, the climate projection for the next decades predict the increase of hydrological drought severity and duration for the three irrigation weirs at Bodri-Juwero, Notog, and Wlingi.

4. CONCLUSIONS

It is concluded that the validation of present data confirms that the drought severity and stress of hydrological drought index follows the same pattern of climate change impact on the area of rice field affected by drought. The best correlations are achieved for drought stress of SRI-12, SRI-1, and SRI-3 for Bodri-Juweoro, Notog, and Wlingi irrigation weirs consequently. Therefore, hydrological drought can be applied to identify climate change impact in the future.

The projected hydrological drought index for the next 30 years at the three irrigation weirs in Java identifies an increasing of drought severity with longer drought duration and worse severity, and consequently more area of irrigated of rice fields will be affected by drought. Extreme drought in Bodri-Juweroro irrigation area is predicted twice with duration of two years, while extreme drought at Notog and Wlingi irrigation weirs will occur more frequently compared to the historical drought. Adaptive strategy should be developed to maintain irrigation productivity under these predicted drought condition.

5. REFERENCES


FRAMEWORK TO ENABLE IRRIGATION DEVELOPMENT TO SUPPORT SMALLHOLDER FARMERS’ CLIMATE RESILIENCE IN THE EASTERN GANGETIC PLAINS

Anton Urfel¹, Timothy Foster², Timothy J. Krupnik³, and Andrew McDonald⁴

ABSTRACT

Groundwater irrigation powered by privately owned electric, diesel and sometimes solar pumps (henceforth private pump irrigation or PPI) plays a critical role in the agricultural development of the Eastern Gangetic Plain (EGP) especially given the largely insufficient and unreliable surface water supplied from public irrigation infrastructure. With increasing climatic variability, the prohibitive costs of building new public infrastructure and the accelerating need to intensify agricultural production in areas outside of the region’s ‘grain basket’ in NW India, suggests that the importance of PPI in the EGP will only increase. At present, many aquifers in the food-insecure parts of the EGP in India, Nepal and Bangladesh remain largely underdeveloped. This constrains farmers’ capacity to adapt to environmental change and weather extremes, and contrasts with other major groundwater systems, where rapid aquifer depletion has garnered global attention. While solar power has become a popular policy fox, we suggest that a balanced look at all PPI is likely to bring broader benefits and utilize existing synergies. To better tackle the challenge of sustainable and equitable water resources development in the EGP, we consider five dimensions of a comprehensive evaluation framework to assess the different components that constitute PPI. Proposed framework components include: (1) aquifer dynamics and pump technology, (2) farming systems characteristics, (3) value chains and social dynamics, (4) policies and institutions, and (5) the data environment to aid both tactical and strategic decision making. While these factors are usually considered in relative isolation by water managers and policymakers, we argue through development of a case study from Nepal that integrated analysis is necessary to develop durable solutions towards sustainable development. Our analysis shows that the PPI has considerable potential to increase the adaptive capacity of agricultural food systems in EGP, with a range of approachable options, including improved understanding of aquifer dynamics and strengthening of agricultural value chains as prerequisite to enable PPI growth. We conclude by highlighting the need for targeted and context-specific development interventions that are informed by integrative and localized assessment rather than generalized approaches to sustainable development.

Keywords: groundwater, surface water, adaptive capacity, drought, water-energy-food nexus, smallholder farmers

1. INTRODUCTION

Groundwater irrigation from privately owned or rented pumps (private pump irrigation or PPI) Plays an important role in enabling smallholder farmers to intensify production and manage risks posed by climate variability and drought. In South Asia PPI has become a major source of irrigation with governments estimate that ca. 60-70% of irrigation in the region stems from groundwater (Shah, 2009). Since canal irrigation...
infrastructure in South Asia is increasingly in disrepair and plagued by governance challenges, it is essential that decentralized PPI systems should be given more priority by policymakers (de Fraiture & Giordano, 2014).

Access to adequate, reliable, and affordable irrigation water is important for smallholder farmers for several reasons. First, irrigation helps farmers to buffer crops against rainfall variability during wet seasons while also enabling additional cropping cycles during dry seasons (Acharjee, van Halsema, Ludwig, Hellegers, & Supit, 2019; Jalota et al., 2012). In doing so, irrigation allows farmers to increase the mean and reduce the variance of production outputs, providing greater certainty about income levels that, in turn, enables greater investment in more remunerative agricultural practices and crops (Lin, 2011).

In some areas, expansion of PPI has led to widespread aquifer depletion, whereas in others, groundwater resources remain underexploited due to limitations to access and utilization that are often caused by high overall risk for investing in agriculture coupled with high cost of irrigation. Treating climate change in South Asia as the new norm requires development trajectories of risk reduction to incentivize farmers to take up sustainable PPI, while avoiding groundwater depletion and ensuring equitable access and use of the resource base. Enabling greater use of groundwater to support food security and rural poverty alleviation is a central goal for governments and donors in the EGP. However, sustainable development of PPI in these regions will require consideration of the complex interlinkages between hydrology, agriculture, economics, governance and other priorities that may differ across different scales such as the household level and state level. This article presents a framework for assessing factor that can influence the sustainable uptake of PPI and further discusses the specific barriers in the EGP and how they could be broken down to facilitate sustainable PPI uptake by smallholder farmers as a climate change adaptation strategy.

Based on this analysis we aim to answer the following questions on PPI based sustainable intensification trajectories in the EGP:

- Where can PPI be expected to make significant contributions increase smallholders resilience to climate change?
- How can policymakers and development practitioners ensure that PPI is equitable and sustainable, and its usage could stay within regional resources limits, i.e. a safe operating space?
- What are the key entry points for scaling up PPI? And what lessons can be learned from neighboring states?

2. PRIVATE PUMP IRRIGATION IN SOUTH ASIA

In the 1990s and 2000s scholars started to explore the impact of PPI on India’s economy and agricultural sector specifically (e.g. Meinzen-Dick, 1996; Aditi Mukherji, 2004; Shah, 1993). The spread of PPI arguably paved the way for the Green Revolution by helping farmers to cope with drought and unreliable surface water replies and therewith mitigate the risk of investing in new technologies and more water sensitive but high-yielding crop varieties (Evenson & Gollin, 2003). (Shah, 2009) points out that access to water through PPI was often exclusive to wealthier farmers and water lords, i.e. de facto monopolies on water supply by landlords with the financial assets to invest in PPI and accompanying high cost of accessing water for resource-constrained farmers, raising concerns about the equity of PPI (Mehta, 2007). The spread of PPI slowly led to the growth of a PPI value chain that drove down costs and increased operational efficiencies. Since then the
accompanying industries such as well drillers and pump manufacturers reduced capital investment and operation costs of PPI. Lower investment and operation costs, in turn, enabled a service provision model that made PPI more equitable. Lastly, rising oil prices cast doubt on the continued equity of PPI (Shah et al., 2009) and solar-powered irrigation systems are being considered as a major strategic solution in the region (Kishore, Joshi, & Pandey, 2017).

On one side, many groundwater resources in South Asia remain underdeveloped and underutilized, although they hold potential to support smallholder farmers (Bharati, Sharma, & Smakthin, 2016; Mukherjee, 2018). One such area is the poor and food insecure Eastern Gangetic Plains (EGP) comprised of Eastern UP, Bihar, and Nepal’s Terai region. Groundwater abstraction in the alluvial aquifers of the EGP amounts to only ca. 20% of sustainable abstraction rates with irrigation being the biggest share. Intensifying irrigation to a level that raises the groundwater abstraction rate to 40% of sustainability limits would move most farmers from life-saving to productivity enhancing and stabilizing irrigation, which is key to meet increasingly erratic rainfall patterns and deteriorating canal irrigation infrastructure that pose great risks to smallholder farmers (Bharati et al., 2016).

On the other side, groundwater depletion rapidly garnered global attention due to the burgeoning groundwater use in South Asia and elsewhere as some aquifers were tapped at rates beyond the natural recharge rates (see (Konikow & Kendy, 2005; Rodell, Velicogna, & Famiglietti, 2009; Wada et al., 2010). In many cases, wealthy farmers and industries would drill and pump water from increasing depths at increasing costs, marginalizing the poor and creating both physical and economic water scarcity. This ‘race to the bottom’ narrative rightfully became a major concern for policymakers (Hoogesteger & Wester, 2015). Nevertheless, this has largely proved to be a highly localized phenomena that is limited to very few districts and regions (Bharati et al., 2016; Abhijieet Mukherji, 2018).

Policymakers and development practitioners should pay adequate attention to the dangers of groundwater depletion, but sustainable and equitable use of underdeveloped groundwater resources should be equally encouraged. Such a perspective is supported by the growing literature and work on issues of access in the EGP (see (Bharati et al., 2016) that highlights the need for a new framework where conditions for the sustainable, equitable, and productive use of PPI are systematically explored.

### 2.1 Areas of an Evaluation Framework

PPI is a complex system composed of social, ecological, technical and hydrological elements. While past research has commonly evaluated these issues independently, here we present a new framework for to analyze the enabling conditions for the sustainable uptake of PPI that considers interacting roles of : (1) the aquifer system, (2) the farming system, (3) the value chains and social dynamics, (4) the policy and institutional environment, and (5) the data environment.

Interlinkages are manifold: For example, robust knowledge on the aquifers is required to gauge the safe operating space and productivity potential of PPI, but the viability of accessing and pumping water are influenced by the farming system and overall water demand. Low resource cereal systems are different to low resource cash-crop system and again to high resource systems. Similarly, possible farming systems are conditioned by the value chains for inputs and marketing of agricultural products which are again tightly linked with the policy and institutional environment. Institutions and policy makers again may only implement appropriate policy if supported by a robust and sufficiently granular data environment. Similarly, well drillers and other
value chain actors may benefit largely from the availability of improved trainings and knowledge management which in turn could bring down irrigation prices and thus increase the flexibility of farmers decision on their farming systems as risks are mitigated.

Figure 1. Framework for enabling private pump irrigation.

1. **Aquifer System and Pump Technology**

Aquifers globally and in South Asia vary widely from unconsolidated alluvial sediments to fractured bedrock. Each aquifer type has specific properties regarding storativity, recharge and flow dynamics. Understanding the aquifer type is crucial to understand its potential to be exploited. PPI for smallholders mostly takes place in unconfined alluvial aquifers in which rivers have deposited layers of sand over long periods of time. These layers can be rather uniform and large or heterogeneous composed of small sand channels that store and exchange water. Some of these aquifers are also artesian where the piezometric pressure is sufficient to lift the water above ground level. The structure of the aquifer also determines the cost and the level of ease of drilling wells depending on the sediments between the sand layers and the amount of rocks in the sediments. This is important to understand as capital investments into tubewell infrastructure can be a major barrier to the equitable access of PPI for smallholder farmers. Technologies to lift water can differ, shallow tubewells operated by diesel pumpsets are widespread in South Asia and other parts of the globe (de Fraiture & Giordano, 2014). But centrifugal pumps in pumpsets may not lift water from deeper than 7m below the pump level. Average water level in the region is ~3 mbgl with ~3m annual fluctuation (Abhijieet Mukherji, 2018). Submersible pumps are slowly spreading but are more expensive and require a reliable electricity connection. These technology aspects should be considered together with aquifer dynamic to better understand abstraction dynamics and sustainability thresholds.

Another key dynamic of the aquifer system are its recharge dynamics. Most aquifers receive their main recharge from a specific area of high permeability that needs to be understood if estimates of sustainable recharge limits are to be trusted. Similarly, aquifer's interaction with river stream, wetlands and other ecosystem components is critical. For example, groundwater can provide a critical amount of baseflow to riverbeds during dry season. Groundwater-surface water interactions should also be considered when estimating a safe operating space for groundwater abstraction by PPI.

2. **Farming System**

Farming system characteristics cruciality for enabling sustainable PPI uptake by smallholders range from general resource endowments, over farmers’ risk attitude,
soil types and management practices. Smallholder farmers (i.e. < 2 ha) are not as homogenous as widely portrayed and small differences in wealth can make substantial differences in the ability to invest and experiment with new technologies such as PPI. Resource poor households may, for example, require targeted support to bring down the cost of PPI to allow equitable access and use.

The crops that are cultivated can also make a stark difference as they differ in drought sensitivity, irrigation requirements at different growth stages and household food security as well as selling price. Maize and rice have substantially different use profiles and sensitivities to drought – sustainable and reliable irrigation thus means different things for both crops. The same is true for soil types and field level hydrology as soils and fields more generally may vary in their water holding capacity and drainage patterns that in turn determine the irrigation needs for equitable access. Lastly, cropping intensity is also crucial and is strongly connected to the seasonality of water availability and intra-annual water table fluctuations. An area may, for example, have perfectly good access to irrigation through PPI in the wet season, but the water table declines heavily during the dry season rendering sustainable and equitable PPI more difficult to achieve all year round.

3. Value Chains and Social Dynamics

PPI value chains are key enablers for the uptake of the technology. Specifically, well-established and low-cost machinery provision channels, mechanics and spare part manufacturers, and local mechanics. Availability of fuel and electricity to run pumps is also of crucial importance given that rural electricity supplies are often inadequate for smallholder and that some remote areas may face fuel shortage in times of especially high demand. However, without a well-functional agricultural value chains in the seed and fertilizer sector as well as market connectivity, PPI alone is unlikely to be taken up by smallholders as general risk level are too high. Similarly, for a well-performing PPI service, provisioning and informal water markets are also dependent on local community dynamics as, for example, social heterogeneity may lower social capital/trust and thus discourage cooperation among water users. Likewise, ease of accessing credit may also play a role. The value chains could be considered as new and climate smart supporting sectors for adapting agriculture to climate change and become, just like renewable energy, a new backbone of the economy.

A key problem is that within an agro-ecosystem, most farmers tend to follow similar cultivation patterns and thus require water at the same time, which increase demand for water, fuel, electricity, boreholes, and pumps. Diversifying agro-ecosystems at the landscape level may thus contribute to more sustainable and equitable uptake of PPI. But collective action can be difficult to achieve.

4. Policy and Institutional Environment

Government subsidy programs can play a crucial role in en- or discouraging PPI. On the one hand, subsidy programs can support farmers that may otherwise not be able to invest in PPI. On the other hand, existing government subsidy schemes may also discourage users that may otherwise privately invest in irrigation as they are waiting to secure government subsidies. It is thus important to be aware of these programs and investigate their potential impact on PPI uptake.

Another key issue of the policy and institutional environment is the knowledge management with regard to better bet irrigation practices. Many farmers that take up PPI have no prior experience with irrigation and can thus benefit from other farmers’ experience that the government can enable to share with them.
A last point is that the institutional environment regarding conflict resolution mechanisms. Oftentimes smallholders may use irrigation services and pay later, e.g. after harvest. A strong institutional environment with clear and reliable rules to settle conflict among participant may thus encourage PPI uptake.

5. Data Environment

Data on groundwater resources as well as use are scarce because of the difficulty to monitor them and the small scale at which PPI takes place. It is virtually impossible to monitor all groundwater irrigation schemes and extremely expensive to operate sufficiently granular monitoring wells in resource poor environments. Much of the knowledge and evidence base on PPI thus stems from extrapolations and estimates. However, establishing clever sampling strategies to better gauge and monitor the actual extent of PPI is crucial for guiding PPI development within a safe operating space that does not transgress sustainability limits while ensuring that sub-regions suffering from specific barriers to uptake are more easily identified and can be more readily supported.

2.2 Case Study: Eastern Gangetic Plains of Nepal’s Terai, Eastern Up and Bihar

This case study will apply the five-element framework to the homogeneous sub-region of the EGP includes the districts north of the Ganges in Eastern UP and Bihar as well as Nepal’s Terai. While some areas feature surface water irrigation schemes that are used by farmers conjunctively with groundwater sources, this paper will focus on areas without access to surface water irrigation to as conjunctive use is limited and pertains to a small an discrete area in the landscape. In surface water irrigation schemes the picture would be somewhat complicated by farmers’ preference to use lower-cost canal water as well as hydrological interactions between the canals and aquifers.

1. Aquifer Dynamics

The aquifers in the study region are largely alluvial with more heterogeneity in the Terai. The Indian part has increasingly homogeneous and productive aquifers (Bharati et al., 2016). The average groundwater table in the region is 4.5 m.b.g.l. at pre-monsoon level with an intra-annual fluctuation of about 2 m. This means that the Terai has good potential for irrigation use through PPI, but more selectively than further South on the Indian side. Ca. 50% of the Terai’s area has good potential for groundwater irrigation as aquifers are not very productive in all of the Terai, likely owing to higher heterogeneity in areas between major rivers, i.e. interfan areas (Bharati et al., 2016).

Centrifugal pumps of diesel pumpsets that make up the main portion of PPI in the EGP have a practical suction head limit of ca. 7 m. While most aquifers are above the level during the monsoon time, some aquifers in the EGP exceed this limit during the dry seasons and thus before monsoon onset. This poses challenges for PPI as higher capital investment costs or reliable electricity supply is required to support PPI in such areas.

The Terai aquifers are recharged from the Bhabar zone at the foothills of the Himalayas where permeability is extremely high and resulting recharge rates are above 1000mm/year for Nepali aquifers. The Indian aquifers are recharged by monsoon rainfall that percolates into the aquifer layers so that recharge rates on the Indian side are around 60% to 70% of recharge rate in Nepal – still comparatively high and only around 45% used. Different recharge patterns also mean that different
approaches are required for guarding aquifer recharge which may reduce of the recharge areas are transformed into built environments or deforested.

![Figure 2. Well hydrographs in the Terai (left) and the Gangetic Plain (right).](image1)

![Figure 3. Aquifer structure in the Terai (left) and the Gangetic Plain (right). Source: (Bonsor et al., 2017)](image2)

![Figure 4. Pre monsoonal depth to water table in India. Red circle indicates Eastern Gangetic Plains. Source: Central Ground Water Board.](image3)

2. Farming System

The EGP is dominated by rice-wheat rotations where rice is grown during the monsoon season between ca. June and October and followed by wheat that is grown
until ca. April. In some areas, rice is also substituted with maize and, more commonly, wheat is replaced with oil seeds, potatoes, pulses, or vegetables. Cash crops are also grown year-round in some pocket areas. Irrigation is especially important for establishing rice nurseries and for land preparation before transplanting rice (Erenstein & Thorpe, 2011). Because climate change increases the exposure of wheat to heat stress in April it is crucial that both rice and wheat are planted in a timely fashion. PPI can play a critical role in supporting timely planting as a lack of water for land preparation constitutes a key bottleneck for rice with cascading effect onto the timing of wheat establishment (Mondal et al., 2013).

Throughout the EGP a wealth gradient exists that decreases in Nepal's Terai from East to West and in Bihar from North to South and Eastern UP being comparatively more wealthy (Erenstein, Hellin, & Chandna, 2010). But generally most households are rather resource poor and high diesel prices are a key hindrance to more equitable utilization of PPI (Shah et al., 2009). This means that variable diesel cost are a key hindrance to the uptake of PPI at scale (Kishore, Sharma, & Joshi, 2014). Focus group discussions that were conducted in the last 3 years suggest that improved pump sizing and operation, improved well drilling techniques and irrigation scheduling at field and village level could go a large way to bring down the cost of irrigation.

3. Agricultural Value Chains, Context & Risk Factors

Agricultural value chains in the EGP are moderately developed. General access to quality seed and fertilizer at affordable prices does exist but varies widely across the geography (Kishore, Sharma, et al., 2014; Park, Davis, & McDonald, 2018). Data on this spatial variation is largely lacking and constitutes one of the key barriers for adequately assessing entry points for sustainable intensification. However, differences between Nepal and India exist. In Nepal the main problem appears to be the insufficient availability of government subsidies and regulated inputs whereas in Bihar the overall level of infrastructure including roads and marketing opportunities increase the overall risk level to an extent that farmers forego opportunities in one sector as the risk that bottlenecks of another input will limit productivity.

The situation is similar for PPI value chains. Most well drillers and mechanics are self-taught and while the market is often assumed to be generally saturated. Farmers nevertheless report that it can be difficult for farmers to avail mechanics, pump shops or spare parts. A sizeable amount of literature on how to increase the energy efficiency of PPI exists, but it is less known how well these are scaled up and adopted throughout the region. Current use and yield patterns suggest that there is room to further leverage improvements identified in existing literature (Bom, van Raalten, Majundar, Duali, & Majumder, 2001). The recent years witnessed and advent of smaller, more portable and energy efficient pumpsets, that is ca. 0.5-0.75 l of fuel per hour pump-sets (Urfels, forthcoming). However, old 5-10HP pump-sets that consume 1-1.5l of fuel per hour still dominate across much of the landscape and the preference for these pump-sets remains a puzzle.

Furthermore, qualitative evidence from field studies suggests that village dynamics vary widely and that some regions are much more heterogeneous in the social setup than others leading to difficulty of marginalized groups to access PPI at adequate prices and timeliness (Wilson, 2006). Scaling up PPI will require a packaged approach where several of these problem sets are monitored and prioritized depending on their importance in different regions with a pro-poor strategy. This is especially important as the benefits of irrigation can often only be realized if communities act together. Landscape pressures such as pests and diseases or blue bulls (large roaming cows that trample and eat crops) would be extremely high for
pioneering adopters as these landscape pressures would focus on their plots, discouraging a transformative change.

4. Policies and Institutional Environment

Many different subsidy schemes have been implemented in the EGP over the last decades that resulted in the construction of many tubewells and purchase of many pump-sets. It is important to note that several of these schemes aimed to provide pump-sets or tubewells to groups of farmers. In practice, however, these are often captured by local elites and become de facto privately-owned machinery. Other subsidy schemes, e.g. fuel subsidies, are often inaccessible and only captured by few elites that are well connected to the local bureaucracy (Kishore, Joshi, & Pandey, 2014). Similar patterns can be found in subsidy schemes of the seed and fertilizer sector.

During fieldwork, many farmers were sporadically probed about conflict solution mechanisms regarding queuing for access to pumpsets or tubewells and the local institutions that manage these. However, most farmers reported that these are harmonious events and priority is given on a first come first serve basis with occasionally favoring farmers with special needs (e.g. extremely dry fields or upcoming family events). And most farmers did report that social capital is highly important for the timely access to PPI. Moving towards sustainable and equitable PPI may thus require some support and build institutions that enable more equitable access to PPI infrastructure so that marginalized population with less social capital can avail institutions to support them for gaining access to PPI.

5. Data Environment

The evidence base on PPI in the EGP is highly variable but generally lacking key information. Data on spatial distribution of PPI and its enabling elements is often absent and if it exists, it is often of dubious quality and public availability. The Central Groundwater Board of India does supply some quality data, but these are far from sufficient to guide bringing PPI to scale. Low-cost and high frequency spatial data collection such as remote-sensing can aid the development of a robust evidence. Existing field level data could be used to cross-check data accuracy and develop approaches to monitor the utilization and extent of PPI. In addition, data on the state of enabling conditions for PPI is crucial to bring PPI to scale and render PPI a ready tool for smallholder farmers in the EGP to deal with climate change as the new norm.

6. Recommendations

Private pump irrigation plays a crucial role for smallholder farmers in the EGP to adapt to climate change as the new norm. But several barriers hinder the uptake of PPI, constraining farmers’ toolset for dealing with climate change. This section presents recommendations on how policymakers and practitioners can use this framework to systematically address barriers that hinder smallholder farmers in the EGP to take up PPI at scale.

First, aquifers in the EGP are highly heterogenous, especially in Nepal’s Terai. But an easily accessible and sufficiently granular database is not available. This greatly limits policy makers and practitioners to appropriately design policy for the conditions that farmers meet in different geographies of the EGP. Once these are known, policy makers and practitioners can provide more appropriate assistance and programming. For example, areas with productive aquifers that however exceed suction limits may benefit more intensively from electricity provision to power submersible pumps. Other solutions, such as positioning the pumps a few meters below ground level with the
motor on ground level may provide another design that is found in a few pocket areas but not widely spread. While India has set into place a monitoring system for groundwater abstraction, this is still absent in Nepal and first steps to monitor groundwater depletion and better understand recharge patterns of Terai aquifers would be a good first step to ensure that PPI remains within a safe operating space. For solar powered irrigation, more research is required on the enabling conditions for different types of the technology.

Second, policymakers and practitioners should seek out different support programs tailored to various farm systems. These can differ in terms of wealth, but also cropping system and soil types and drainage types. Different types of PPI such as solar or efficient diesel pumps are likely adequate in different circumstances. Farmers are unlikely to take up PPI just for the sake of it. But when their livelihood strategies and the farming systems they manage are taken into account, PPI can address specific problems that water users have. If these are appropriately understood and a business case is made, it likely to be easier to provide support programs that effectively solve problems for users through the use of PPI. Resource-poor farmers likely benefit most from bringing down the cost of irrigation, which may also spur the development of water provision services. Lowland areas that are constrained to rice-based systems because of flooding during monsoon rain events, for example are likely to benefit extensively from supporting farmers from timely planting, but not so much from irrigation during drought. These dynamics need to be taken into account when thinking about costs and benefits of PPI.

Third, many of the benefits of PPI stem from a greater flexibility in farm management decisions as climate risks become mitigated. If, however, other value chain sectors such as market connectivity, seed supply, fertilizer supply, or tillage machinery are the key bottlenecks, PPI is unlikely to be taken up at scale unless bottlenecks are addressed before policy makers and practitioners can expect farmers to adopt PPI at scale. Likewise, some landscape dynamics such as pest and disease pressure and Bihar’s locally famous blue bulls require collective action and simultaneous uptake of similar practices. Policymakers and practitioners can identify areas where this is the case and facilitate such processes, a strategy that may be especially useful in village with low social capital.

Fourth, while we do not advocate against abolishing capital subsidies for tubewells, we note that these have not proved extremely effective in bringing PPI in the EGP up to scale. However, governments can play a major role in breaking down management through leveraging existing extension networks and cooperating with the private sector to educate and train actors along the entire value chain to drive down prices in the PPI sector and allow farmers to take PPI up to adapt to a changing climate. Similarly, practitioners can ensure that local institutions for adequate management of PPI are in place or facilitate their emergence.

Fifth, one of the main bottlenecks in the EGP remains widespread data scarcity on the elements that enable PPI uptake at scale. Policymakers and practitioners can thus work together to assemble an adequate evidence base that allows targeted support to different farmers across different geographies in the EGP. Smartphone and satellite technologies together with mobile survey can provide low-cost channels to gather such data and continuously monitor them.

3. CONCLUSION

In conclusion, PPI is a complex and new phenomenon that has been studied over the last three decades. While it partially enabled the Green Revolution to take place, much of the global attention has been focused on its impact on depleting groundwater...
resources. Several regions, however, remain unexploited. While we may not yet fully answer the three questions that this article poses at the beginning, we provide initial information and recommendations on finding the answers. In this light, this article presents a framework for identifying barriers to the sustainable and equitable uptake of pump irrigation in the Eastern Gangetic Plains at scale and provides recommendation of how policymakers can break these down. A key feature is that these elements are interconnected and while improvements on one aspect may have positive effects on another aspects, existing bottlenecks in other aspect may also limit the effectiveness of a single intervention. While such community-based approaches are not new, this article provides a framework under which a regional support and evidence base on key factors inhibiting PPI uptake may be assembled and allow the identification of context-specific intervention at different location across the geography. Since the evidence base is still highly incomplete, a two-tiered approach that one the one hand seeks to establish a more robust and granular evidence base and on the other hand initiate programs in areas where information of the bottlenecks is available. These develop further synergies and constitute the backbone of PPI as a critical technology for smallholder farmers to adapt to a climate change that is becoming the norm. We already started data collection and analytic efforts and will increase these in the future. We seek to combine different data from different sources such as survey data, land & water model outputs, remotely sensed data, participatory appraisals and in-field and on station technology testing to move to knowledge frontier and better understand how the region can be put on a sustainable transformation pathway. For example, an agricultural machinery promotion and testing center has been established in Nepal’s Terai and is hosted under the Ministry of Agriculture in close cooperation with our workstreams. At the same time, baseline survey collection on irrigation use and livelihood outcomes in combination with in-field testing is under way. In addition, several agronomic survey and participatory data sources are currently being analysed to better understand how to bring benefits of irrigation to scale in the IGP. To properly address the challenges, however, larger partnerships and consortia are required to scale up smallholder irrigation in a way that transforms the region’s agro-ecosystems into climate resilient and sustainable ones.

4. REFERENCES


THE COUNTERPLAN TO CLIMATE CHANGE IN AGRICULTURAL INFRASTRUCTURE IN KOREA

Park Tae Seon¹, Jeong Kyung Hun² and Song Suk Ho³

ABSTRACT

Recently, our country has been affected by climate change which causes the increase in drought intensity, drought duration, water deterioration and flood risk. Climate change impact has damaged agricultural environment, especially, for agricultural water demand and water supply management. Therefore, efforts made to minimize climate change damage such as; ‘water supply diversification’, ‘flooded farmland improvement’, ‘irrigation facility reinforcement’, ‘water quality improvement’, ‘accelerating facility management manual’, ‘intelligent water management’ and so on. “Climate Change Investigation” project established in 2017 to figure out how much agricultural water demand change and water supply management are affected by climate change historically. According to this investigation, annual average temperature has increased while annual average precipitation has decreased. In addition, not just only evapotranspiration but also paddy irrigation requirement, field irrigation requirement have increased during the recent 3 years compared with the past situation.

The recent water demand change has affected water supply management. Water level during irrigation has recently decreased. Moreover, drought intensity and drought duration have got worsen. The results indicate that there are differences regionally such as drought impact areas or flood impact areas.

To adapt to climate change and minimize the damage, “Climate change investigation” will continue and apply it at ‘National Climate Change Adaptation Measures’. Accordingly, we can cope with climate change impact efficiently.

Keywords: Climate change, Climate change investigation, Agricultural water demand, Water supply management, Drought impact, Flood impact.

1. INTRODUCTION

Recently, Korea has been affected by climate change in common as well as worldwide countries. Regional differences have become more deepened in regard to drought and flood impact by the change of rainfall pattern and intensity. Climate change causes a lot of damages to agriculture, forest, health, industry, energy and so on. But agriculture is particularly damaged more than the others because it exposed by natural environment.

In order to not only protect the people and property from climate change impact but also keep safe, Korea established “National Climate Change Adaptation Measures” in 2011. After that, the measures in accordance with society condition in 2016 were made. Then, establishment of the new national adaptation measures will be in 2021. Besides, as a representative of agricultural water supply and infrastructure management, KRC (Korea rural community corporation) has performed “Climate

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Change Investigation* which analyse the change of agricultural water demand and infrastructure impact regionally. The investigation has been started since 2017. This project lasts every year and is going to assess climate change vulnerability in 2020. This assessment result will be applied at new national adaptation measures in 2021.

Through this investigation, figure out recent change compared with the past situation such as temperature, evapotranspiration, water requirement, drought situation, flood situation in infrastructure and so on. The purpose of this manuscript is to show the result of climate change impact to agricultural water and infrastructure through analyse “Climate Change Investigation”. The approach taken is analysis of items as stated above which is compared an average of the recent 3 years (2016~2018) with an average of the past 10 years (2005~2010) or an average of the past 30 years (1981~2010). Climate data is compared with an average of the past 30 years and Infrastructure data is compared with an average of the past 10 years because the infrastructure data has not been accurately measured until 2002.

2. SUBJECT SELECTION

First of all, a need to decide the scope of investigation and subject for analysis is essential. Korea divides agricultural water supply areas into 511 areas. Therefore we finally have chosen 393 areas except for 118 areas which have been urbanized. Urban areas excluded due to a small amount of agricultural water requirements.

<table>
<thead>
<tr>
<th>Name of province</th>
<th>Areas</th>
<th>Selected</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>GyeongGi</td>
<td>68</td>
<td>46</td>
<td>68%</td>
</tr>
<tr>
<td>GangWon</td>
<td>57</td>
<td>42</td>
<td>74%</td>
</tr>
<tr>
<td>ChungcheongBuk</td>
<td>36</td>
<td>32</td>
<td>89%</td>
</tr>
<tr>
<td>ChungcheongNam</td>
<td>46</td>
<td>40</td>
<td>87%</td>
</tr>
<tr>
<td>JeollaBuk</td>
<td>46</td>
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<td>78%</td>
</tr>
<tr>
<td>JeollaNam</td>
<td>100</td>
<td>74</td>
<td>74%</td>
</tr>
<tr>
<td>GyeongsangBuk</td>
<td>76</td>
<td>64</td>
<td>84%</td>
</tr>
<tr>
<td>GyeongsangNam</td>
<td>71</td>
<td>55</td>
<td>76%</td>
</tr>
<tr>
<td>JeJu</td>
<td>11</td>
<td>4</td>
<td>36%</td>
</tr>
<tr>
<td>Total</td>
<td>511</td>
<td>393</td>
<td>77%</td>
</tr>
</tbody>
</table>

**Figure 1.** Province list and 393 agricultural water supply areas chosen

In addition, 462 agricultural infrastructures are chosen (246 reservoirs, 131 irrigation pumping stations, 85 drainage pumping stations) in each city of province in order to analyse climate change impact considering water supply management from infrastructure.

**Table 1.** 462 agricultural infrastructures to analyze climate change impact

<table>
<thead>
<tr>
<th>Group</th>
<th>Total</th>
<th>GG</th>
<th>GW</th>
<th>CB</th>
<th>CN</th>
<th>JB</th>
<th>JN</th>
<th>GB</th>
<th>GN</th>
<th>JJ</th>
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<td>Rsv</td>
<td>246</td>
<td>33</td>
<td>21</td>
<td>21</td>
<td>29</td>
<td>22</td>
<td>42</td>
<td>41</td>
<td>35</td>
<td>2</td>
</tr>
<tr>
<td>Ips</td>
<td>131</td>
<td>22</td>
<td>9</td>
<td>10</td>
<td>15</td>
<td>12</td>
<td>22</td>
<td>22</td>
<td>18</td>
<td>1</td>
</tr>
<tr>
<td>Dps</td>
<td>85</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>14</td>
<td>9</td>
<td>18</td>
<td>15</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>462</td>
<td>61</td>
<td>34</td>
<td>36</td>
<td>58</td>
<td>43</td>
<td>82</td>
<td>78</td>
<td>67</td>
<td>3</td>
</tr>
</tbody>
</table>
3. RESULTS

3.1 Change in Demand for Agricultural Water by Climate Change

Among the various items analyzed, it is defined that reference value is an average of the past 30 years (1981~2010) and comparison value is an average of the recent 3 years (2016~2018) in order to figure out the recent change of each item by contrast with the past 30 years.

The annual average temperature has increased by 0.7℃ during the recent 3 years compared with the past 30 years. Heat wave days also have increased by 13.4 days. On the other hand, annual average precipitation has decreased by 117mm during the recent 3 years compared with the past 30 years.

Particularly, precipitation between June and August has decreased by 183 mm during the recent 3 years which means most of precipitation decrease occurs in this period. On the other hand, paddy should be supplied 60~70% of agricultural water in this period. The result indicates that there is a problem about water supply management more than before as time goes by.
Available precipitation days have also decreased by 3.4 days during the recent 3 years. But torrential rainfall days have just decreased by 0.4 days which is similar with the past 30 years. Above results indicate that the recent climate situation in Korea affected drought more than flood due not only to temperature increases but also precipitation decreases.

\[\text{Figure 4. Precipitation variation, available precipitation days and torrential rainfall days}\]

As a consequence of climate change above, demand for agricultural water has changed. Evapotranspiration has increased by 49mm during the recent 3 years in most of areas. Moreover, paddy irrigation requirement have increased by 213mm and field irrigation requirement have also increased by 90mm during the recent 3 years. As the evapotranspiration, demand for paddy and field irrigation requirement got larger than before at the most of areas.

\[\text{Figure 5. Evapotranspiration, paddy irrigation requirement, field irrigation requirement in different provinces}\]

3.2 Change in Impact for Agricultural Infrastructure by Climate Change

As stated above, it has affected water supply management in agricultural infrastructure by evapotranspiration and irrigation requirement increases. As evapotranspiration and irrigation requirement increase, it would become more important to manage water supply and irrigation control due to lack of water at infrastructure. Therefore, water level before irrigation, water level after irrigation, annual lowest water level, number of days in Alert & Serious level, number of days in
full water level at reservoir were analyzed. In addition, we analyzed irrigation and drainage impact from pumping stations. Moreover, it is planning to focus on the reservoir impact.

3.2.1 Water Level before and after Irrigation

Through the water level before irrigation, it could assess the capacity of water security. Upon investigation, water level before irrigation was over 80% at the most of reservoirs because precipitation during Sept-Dec, Jan-Feb has increased in spite of annual average precipitation decrease. This result indicates that capacity of water supply before irrigation has kept well compared with the past 10 years.

Figure 6. Variation of water level before irrigation in different provinces

Besides, it could assess the capacity of water restoration through the water level after irrigation. As the evapotranspiration has increased and precipitation has decreased during June-August, Water level has decreased at some of reservoirs compared with the past 10 years. At Chungcheongnam province, the water level after irrigation was under 60% during the recent 3 years whereas it was over 80% in the past 10 years. That is the reason why this region recently has gone through difficulty of water supply management.

Figure 7. Variation of water level after irrigation in different provinces

3.2.2 Annual Lowest Water Level and the Number of Days in Alert & Serious Level

Through the annual lowest water level during irrigation, we could assess the drought intensity. Upon investigation, the annual lowest water level has decreased at the most of reservoirs during the recent 3 years compared with the past 10 years due to
precipitation decrease. Especially, at Chungcheongnam province, the annual lowest water level was 50% at least in the past 10 years but recently it has decreased to 35% so that drought intensity got larger than the past situation.

Through the number of days in alert & serious level, it could assess the drought duration. It is defined that the number of days in alert level is counting the day of water level under 60% and the number of days in serious level is counting the day of water level under 50% by emergency management manual. At some of reservoirs, the number of days in alert & serious has increased during the recent 3 years but the others have not. Especially, at Chungcheongnam, Gyeonggi, Jeollanam province, it has increased remarkably. On the other hand, it has decreased at Gangwon, Jeollabuk province.

Through the number of days in full water level, we could assess the flood risk. It turned out that there were regional differences. At Gyeonggi, Gangwon, Chungcheongbuk, Chungcheongnam, Gyeonggsangbuk province, the number of days in full water level has decreased during the recent 3 years compared with the past 10 years. Meanwhile, it has increased at Jeollabuk, Jeollanam, Gyeongsangnam, Jeju province during the recent 3 years. Especially, At Gyeonggi province, it has
decreased by 32 days so that the flood risk has reduced while it has increased by 30 days at Gyeongsangnam province.

![Number of days in full water level](image1)

**Figure 10.** Number of days in full water level in different provinces

4. CONCLUSIONS

This investigation indicated that the climate pattern has changed unlike the past situation and possibility of drought impact or flood impact has increased regionally. Specifically, Infrastructures at Gyeonggi and Chungcheongnam province would be affected by drought while infrastructures at Gangwon and Jeju province would be affected by flood. Since precipitation between June and August has decreased during the irrigation period, the drought intensity and duration got worse than the previous situation so that we need to prepare specific measures about how to minimize negative impact.

As every country does, Korea has been striving to adapt to climate change. A lot of projects such as ‘water supply diversification’, ‘flooded farmland improvement’, ‘irrigation facility reinforcement’, ‘water quality improvement’, ‘accelerating facility management manual’, ‘intelligent water management’ and so on is being implemented. The purpose of those projects is to supply water to paddy stably and protect damage from flood, to keep the infrastructure safe from natural disaster regarding climate change.

![Coping plan for agricultural infrastructure](image2)

**Figure 11.** Coping plan for agricultural infrastructure

At that time of planning those projects in 2013, it did not include some of areas affected hugely by climate change because we did not have enough data. But since
we have started “Climate Change Investigation”, it is possible to build data and consider the climate change impact in detail.

In 2020, it is going to perform climate change vulnerability assessment based on the results of this investigation. After that, we are going to compare the result of assessment with climate change risk proposed from "National Climate Change Adaptation Plan".

It is necessary to check up the present adaptation capacity and divide areas in detail such as drought or flood vulnerable area. Furthermore, it is essential to analyze future climate change impact using scenario and figure out water demand change so that we can cope with water supply management properly.

It is also necessary to analyze constantly in order to build climate data enough. As shown, climate change has already approached near our life and we should prepare how to adopt this situation right away.

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FLOOD RISK ASSESSMENT DUE TO THE IMPACT OF CLIMATE CHANGE UNDER DEVELOPMENT OF BASIN INVESTMENT PLANS (DBIP), CLIMATE RESILIENCE IMPROVEMENT PROJECT (CRIP)


ABSTRACT

Sri Lanka has currently experienced the impact of Climate Change. High-intensity rainfall events which cause massive floods and low or no rainfall for a longer period which leads to the drought condition is common in some part of Sri Lanka. Therefore DBIP study under CRIP has been introduced to investigate the Climate Change impacts in selected 10 river basins in Sri Lanka. Under this study, flood and drought risk associated with the 10 river basins will be assessed and risk mitigation interventions will be proposed to reduce the risk damages. This paper describes the methodology used in flood risk assessment under CRIP – DBIP study.

Flood risk assessments were carried out for seven scenarios; Case 01 is for the baseline condition to show the risk associated with the basins for current condition, Case 2-4 scenarios are to analyze the risk associated due to Climate Change in the basins for the current condition under 03 cases (Pessimistic, Optimistic and Average), Case 5-7 scenarios are to analyze the risk associated due to Climate Change with the basin developments in the year 2040. Developed flood models were used to get the flood hazards for the seven scenarios and collected exposure data together with developed depth-damage functions were used to calculate the associated flood risk in the basin. Calculated Annual Average Damage (AAD) from the results of flood risk, was mapped spatially. These are to be used in planning and decision making of flood mitigation interventions in order to minimize the economic loss to the country due to floods which are currently being experienced.

Study results shows that flood risk in all river basins increased due to the impact of Climate Change and the risk is further increased due to the developments / urbanization of the river basins.

KeyWords: Climate Change, Flood Risk Assessment, Damage Assessment, Pessimistic, Optimistic, Annual Average Damage (AAD)

1. INTRODUCTION

CRIP was introduced to Sri Lanka as Sri Lanka has been experiencing the impacts of climate change in recent times. This project is the entry point to find out the short term and long term solutions to the flood and drought risk due to climate change. CRIP has two main components. Component 1 is aimed to find out long term solutions for flood and drought risk associated with selected 10 river basins under the Development of Basin Investment Plans(DBIP) study while Component 2 aims to implement critical climate risk mitigation interventions in irrigation, transport infrastructure and school sectors which were damaged from recent floods and landslide which are short term solutions.

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10 river basins were selected for the DBIP study considering the several facts like historical flood and/or drought issues and their severity, damages to the public and private properties, and potential for water resources development. Selected river basins are: (i) Kelani Ganga; (ii) Attanagalu Oya; (iii) Nilwala Ganga; (iv) Gin Ganga; (v) Malwathu Oya; (vi) Mahaweli Ganga; (vii) Maha Oya; (viii) Deduru Oya; (ix) Kala Oya; and (x) Gal Oya (Figure 1 below). Studies for first six (6) river basins have been completed under the Phase-I of the study and the balance four (04) basins have to be carried out under the Phase-II of the study. Altogether the selected 10 river basins covers 42% of Sri Lanka while 28% is covered from Phase-I river basins.

Sri Lanka has divided into three climatic zones considering the average annual rainfall of the areas such as Wet (>2500 mm), Dry(<1750 mm) and IntermEDIATE zone. Out of the six river basins in Phase-I, Kelani ganga and Gin ganga lie completely in the wet zone whereas Malwathu Oya lies completely in the dry zone. Attanagalu Oya and Nilwala ganga lie in both wet and intermediate zones while Mahaweli Ganga; the largest river basin in Sri Lanka lies in all three climatic zones. This paper describes the flood risk assessment carried out for the first six river basins under CRIP – DBIP study.

![Figure 1 Selected 10 river basins for CRIP DBIP Study](image)

2. METHODOLOGY

DBIP study assessed the flood risk associated with a selected river basin for seven (07) cases as mentioned below.

a) Current climatic conditions, land use, water demand, irrigation practices, hydraulic infrastructure and reservoir operation (Case 1, Base Case)

b) Future climatic conditions (3 scenarios - Pessimistic, Average & Optimistic) and current land use, water demand, irrigation practices, hydraulic infrastructure and reservoir operation (Cases 2, 3, 4).

c) Future climatic conditions (3 scenarios - Pessimistic, Average & Optimistic), and projected land use (2040), water demand, irrigation practices, hydraulic infrastructure and reservoir operation (Cases 5, 6, 7).
Table 1 - Selected seven scenarios for Flood Risk Assessment

<table>
<thead>
<tr>
<th>Climatic Conditions</th>
<th>Basin Development</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Current “No Basin Development”</td>
</tr>
<tr>
<td>Current Climate</td>
<td>Case 1 (Base Case)</td>
</tr>
<tr>
<td>Future Climate</td>
<td>Pessimistic Case 2</td>
</tr>
<tr>
<td></td>
<td>Average Case 3</td>
</tr>
<tr>
<td></td>
<td>Optimistic Case 4</td>
</tr>
</tbody>
</table>

The overall work plan for flood risk assessment is shown below in figure 2.

![Figure 2 - Overall Flood Risk Assessment Process](image)

TuFLOW is used as the flood modelling software. Developed flood models were used for each of the basins with appropriate Digital Elevation Models (DEMs), land use and the soil to analyse the risk for the base case. These models were calibrated and validated with observed flow / depth of known flood events. These validated models were used to analyse the risk for different return periods (2, 5, 10, 25, 50, 100 & 200 years). Development of rainfall packages, used in the flood models for different return periods is described in section 2.1.

2.1. Hydrological Inputs

Development of rainfall packages for different return periods are the major component of this assessment and it consist of four (04) elements as mentioned below:

- Rainfall Depth – Rainfall depths for selected rain gauges in river basins were calculated for the various return periods from Intensity-Duration-Frequency (IDF) analysis for the two distributions of Gumbel / EV1 and Pearson Type III.
- Rainfall storm duration – This was selected after analyzing the historical flood events occurred in each basin (eg. 3 days, 4 days, 5 days).
- Storm Profile – Two basin-wide storm profiles; ‘high intensity’, and ‘low intensity’ were selected for a basin after analyzing the storm profiles of the sub-daily rain gauges in and around a basin. ‘Moderate intensity’ profile was
obtained by averaging high intensity and low intensity rainfall profiles. Altogether three storm profiles were taken as storm profiles. An example of selected basin-wide profiles are showing below (Figure 3).

![Figure 3 - Derived basin-wide ‘high intensity’, ‘low intensity’ & ‘moderate intensity’ Rainfall profiles](image)

rainfall depths at each rain gauge to make sure that design rainfall event does not occur at the same time for all rainfall stations in a basin.

Using above-developed data, it can create a lot of combinations of rainfall packages for one return period (eg. 2 year return period; 2 (rainfall depths from EV1 and PIII) x 3 (storm durations) x 3 (storm profiles) = 18 combinations). All the rainfall packages for design return period (SoP-Standard of Protection of the basin) were applied to the calibrated TuFLOW model and analysed the results of separate runs for the design return period. Most suitable combination for the design return period was selected considering the statistical flow (which has almost the same statistical flow value), shape of the hydrograph and the volume of the hydrograph at key monitoring stations (river gauges). The selected rainfall package (combination of distribution, storm duration and rainfall profiles) was applied to other return period also.

2.2. Flood Damage Assessment

The selected combination for each of the return periods was applied for the analysis of flood risk for the base case (case 01). Model output for each of the return periods (flood depths and inundation area) together with collected exposure data and developed depth-damage functions (building, building contents, vehicles, infrastructures, etc) were used to calculate the flood damages. An example of depth-damage function for buildings is shown below in Figure 4.

![Figure 4 - Depth Damage Function for Buildings](image)
2.3. Economics of Flood Risk

From the results of the flood damage assessment for each of the return periods of Case 01, flood damage exceedance probability curves were plotted in order to calculate the Annual Average Damage (AAD) for a river basin. The area under the curve is calculated as AAD for the base case which represents the average damage due to a flood in a particular basin which could be expected in any given year. Flood damage exceedance probability curve for Case 01 is shown in below Figure 5.

![Flood damage exceedance probability curve for Case 01](image)

**Figure 5 - Flood damage exceedance probability curve for Case 01**

2.4. Application of Climate Change

Flood risk assessment for Case 01 is described above in Section 2.1 to 2.3. Under Case 02-07 the flood impact was analysed due to the climate change for the current condition and future developments. In order to get the climate change factors, stochastic weather generation tool was used and observed weather data fed as input data to the tool. This tool produced baseline & 10 climatic change daily rainfall data series for 99 years at a specific location. These 10 climatic series were generated from the available Global Circulation Models (GCM) associated with the Representative Concentration Pathways (RCP). Three climatic factors were selected for three climatic scenarios (Pessimistic, Optimistic and Average) for each basin for each return periods out of 10 generated climate change daily rainfall data series after comparing the statistical rainfall depths changes with the baseline values (higher rainfall depth change factor as “Pessimistic”). Rainfall packages selected under section 2.1 for different return period were multiplied by the climate factors for three scenarios. Selected Pessimistic climate change factor applied for Case 2 and 5 defined above. Optimistic climate change factor applied for Case 4 and 7 while Average climate change factor applied for Case 3 and 6.

2.5. Application of Basin Development

Case 05-07 analyses the flood risk due to climate change and future development by 2040. Application of climate change for these three cases is described in Section 2.4. The major difference for these three cases was due to the basin development in 2040 in the flood models. Land use and the soil changes for 2040 was applied to the model and the potential water resources and infrastructure development that will be implemented by the year 2040 was applied. Then applied the selected climate change factors under section 2.4 and run the flood models. Model output for each return period (flood depths and inundation area) together with developed/expected exposure data for 2040 (population, new buildings, etc) and developed depth-damage functions were used to calculate the flood damages for the Case 05-07.
These flood damages then converted to monetary terms based on the future economic values as described under Section 2.3.

3. RESULTS

Flood damages were assessed for various economic assets such as roads, railway/embankment, agriculture, building fabric, building Contents, and vehicles for each of the river basins. Results for one of the river basins (Gin Ganga) for various economic assets are shows in Table 2 and Figure 6 below.

Table 2 - Average Annual Damages to the Gin Ganga Basin Due to Flood for 07 cases

<table>
<thead>
<tr>
<th>Economic Asset</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
<th>Case 6</th>
<th>Case 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads</td>
<td>0.64</td>
<td>1.27</td>
<td>1.14</td>
<td>1.1</td>
<td>1.42</td>
<td>1.29</td>
<td>1.24</td>
</tr>
<tr>
<td>Railways/Embankment</td>
<td>0.03</td>
<td>0.05</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Agriculture</td>
<td>2.53</td>
<td>2.9</td>
<td>2.65</td>
<td>2.57</td>
<td>2.43</td>
<td>2.23</td>
<td>2.16</td>
</tr>
<tr>
<td>Building Contents: Other</td>
<td>1.2</td>
<td>1.61</td>
<td>1.35</td>
<td>1.24</td>
<td>3.8</td>
<td>3.42</td>
<td>3.26</td>
</tr>
<tr>
<td>Vehicles</td>
<td>0.0</td>
<td>0.01</td>
<td>0.0</td>
<td>0.0</td>
<td>0.71</td>
<td>0.6</td>
<td>0.57</td>
</tr>
<tr>
<td>Average Annual Damage</td>
<td>20.35</td>
<td>26.87</td>
<td>25.61</td>
<td>21.47</td>
<td>31.59</td>
<td>27.22</td>
<td>25.74</td>
</tr>
</tbody>
</table>

Figure 6- Annual Average Damage to the Gin Ganga Basin Due to Flood

Based on the results tabulated in Table 2, three cases are considered to be more important to make the comparison in the decision making process for flood mitigation. Case 01 is the most important case since it represents the actual situation of the present flood risk with the present climate and present development status. Case 02 is the next important case as it represents the highest flood risk due to the impacts of pessimistic climate scenario. Other important case is Case 05 as it represents the highest flood risk due to the impacts of pessimistic climate scenario in combination with the expected development changes in the year 2040. Accordingly, the results of Case 01, Case 2 and the Case 05 have been tabulated in the Table 3 and graphically represented in Figure 7 for all six Phase-I river basins.
Table 3 – Annual Average Flood Damages of Phase - I River Basins.

<table>
<thead>
<tr>
<th>River Basin</th>
<th>Case 01 Current Cost</th>
<th>Case 02 Cost of Climate Change</th>
<th>Case 05 Cost of Future Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kelani Ganga</td>
<td>240</td>
<td>282</td>
<td>363</td>
</tr>
<tr>
<td>Attagalag Oya</td>
<td>23</td>
<td>28</td>
<td>65</td>
</tr>
<tr>
<td>Nilwala Ganga</td>
<td>60</td>
<td>78</td>
<td>100</td>
</tr>
<tr>
<td>Gin Ganga</td>
<td>20</td>
<td>27</td>
<td>32</td>
</tr>
<tr>
<td>Mahaweli Ganga</td>
<td>7</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Malwathu Oya</td>
<td>7</td>
<td>11</td>
<td>12</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

According to the study results, the highest flood damage is currently experienced in the Kelani Ganga basin. This is because the Kelani basin receives more rainfall since it lies completely in the wet zone and most of the basin area is covered by the two most densely populated districts of Sri Lanka (Colombo and Gampaha). Therefore, flood damages and affected population are very high. Second highest flood damage is in the Nilwala Ganga Basin. This is because Nilwala basin also receives high rainfall since most of the basin lies in the wet zone and most of the basin area is covered by one of the third most densely populated districts of Sri Lanka (Matara). Third highest flood damage is in the Attagalag Oya Basin. Eventhough most of the basin lies in the wet zone and most of the basin area is covered by the second most desely populated district of Sri Lanka (Gampaha), its flood damage is lower than others due to the small basin area. Gin ganga basin lies completely in the wet zone and the basin area is mostly covered by one of the third most densely populated districts of Sri Lanka (Galle). But the resultant flood damage is very low compared to the other three basins. This is because, Gin Ganga basin has been strengthened against the flood to some extent. Flood damages in the Mahaweli Ganga and Malwathu Oya is even lower due to the low rainfall that the basin receives and the low population densities of the cities within these basins.

And also the results show that the cost of flood damages in all river basins would be increased due to the climate change and this could be further increased due to the
developments in the basins expected by the year 2040. Accordingly, this indicates that all the six river basins need to be developed against the floods in order to reduce the economic loss to the country that happens annually due to the floods.

5. REFERENCES


IMPACT OF CLIMATE CHANGE ON GROWING SEASON AND AGRICULTURAL WATER MANAGEMENT IN ONTARIO

Ramesh Rudra¹, Trevor Dickinson², Rituraj Shukla³ and Shiv O. Prasher⁴

ABSTRACT

Climate change has impact on various hydrologic variable. It includes temperature and precipitation characteristics. In temperate and humid regions like southern Ontario, the effect of climate change on hydrologic variables are unique. The average annual temperature is going up but the extreme increase is in the winter temperature. Winter average temperature is going up by about 2°C over 70 years of period. However, extreme daily minimum temperature is going up by more than 3°C. This climate effect has great impact on the nature of precipitation and length of frost-free days. The snowfall over winter months is decreasing and the rainfall is increasing. The number of frost-free days during late fall months, early winter months, late winter months and early spring months are increasing. This is resulting in an increase in length of the growing season. This research focuses on the effect of change in hydrologic variables on agricultural water management in Ontario. The special attention is given to the impact on available surface water (stream flow, ground water recharge) quantity and water quality (soil erosion and sediment loads).

Keywords: Climate change, Minimum Temperature, Frost-free days, snowfall, southern Ontario

1. INTRODUCTION

The change in hydrological regimes such as temperature, evapotranspiration and precipitation etc., has serious impact on the agriculture water management sector. In agriculture, the climate change has significant effect on plant water requirement, water quality and available moisture content in the soil. These effects were recently report in serval reports worldwide (Kundzewicz, et al 2007; Bates et al. 2008; Nelson, et al 2009; IPCC 2013 and 2014; Rudra, et al., 2015 & Neelin, et al., 2017). Agriculture sector has been noticeably affected by extreme climate events almost in every region of the world. The changing climate affects the frequency, intensity, duration of weather event, and variation in long-term trend of climatic variables. The long-term effects include a decrease in sea ice and an increase in permafrost thawing, an increase in heat waves and heavy precipitation, and decrease in water resources in semi-arid regions. The frequency and intensity of these events are likely to be amplified in the future (IPCC 2012 & Alonso et al., 2017). At present, some studies show that over the past 50 years there has already been an increasing trend of the various climate excesses, such as an increase in the number of unusually warm days and nights at the global scale, a pole-ward shift in extra-tropical cyclones, an increase of the number of heavy precipitation events in some regions, and earlier occurrence of spring peak river flows in snowmelt and glacier-fed rivers (Rosenzweig, et al 2001; Tubiello, et al 2007; Piao, et al 2010; Schaap, et al. 2011; Lobell, et al.

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The magnitudes of climate extremes, especially to agriculture, which depends severely on weather events, have received wide attention in the scientific community.

In Canada, climate data from many thousands of stations spanning all provinces and territories is freely available from Environment Canada’s historical weather database (ECCC 2015 & EPA 2016). For example, national agencies, such as the Agriculture and Agri-Food Canada (AAFC) and Ministry of Environment (MOE) maintains a huge dataset from various study. Data of two climate variables which are specifically important to the Canadian landscape are ‘Minimum Daily Temperature’ (MinDT) over winter period and Frequency of ‘Frost-Free Days’ (FFDs). The MinDT is the lowest recorded temperature on a given day. The frequency of FFDs can be defined as the number of days the MinDT exceeds zero degrees Celsius (0°C) during winter period, or in other words the number of days when water near the surface will not freeze (Bonsal, et al. 2001). MinDT and the frequency of FFD’s are of particular interest to sectors that are highly dependent on the hydrologic cycle such as agriculture and local/urban watershed management. When temperatures are at or below 0°C, precipitation falls on the earth’s surface as snow, and when temperatures are above 0°C the snow storage melts and the precipitation is in the form of rain. The melt-water is released and travels through various hydrological processes to surface waters, soil, and groundwater (Bonsal, et al. 2001; Yagouti et al. 2008 & Ahmed et al., 2014).

When the MinDT and frequency of FFD’s change with the climate, the distribution of water within the hydrologic cycle will also change thus, there is the potential for previous hydrologic patterns to change dramatically (Cooter and Leduc, 1995 & Calzadilla, et al. 2013). Also, as the MinDT’s and frequency of FFD’s change, so it will affect the heat units available for plant growth (Easterling & Apps 2005). The change in MinDT’s and frequency of FFD also creates some challenge. It includes changes to growing season length and position on calendar, changes to plant hardiness zones, changes in rapid and base flow components of the stream flow, return period, and magnitude and timing of groundwater recharge and storage (Jarvis & Stuart 2001).

Although there is an abundance of research on the consequences and modeling of climate change at a global level, there is still much work needs to be done to translate these consequences at the regional level, which would allow for the development of practical solutions in affected sectors. A wave of research beginning in the 1980’s focused on analyzing daily temperature extremes on a regional level (Karl, et al 1993; Brazdil, et al. 1996; Manton, et al. 2001; Klein & Können, 2003; Rogers, et al 2007 & Neelin, et al., 2017). This research relates to the overall yearly trends, and seasonal trends analysis of climatic variable for many stations around the world using variety of different methods. Much of this research has focused on uncovering the relationships between temperature extremes and other physical parameters. There has been little to no focus on observing extreme temperature data alongside important temperature thresholds such as 0°C between rain and snow.

In this study, the influence of changing climate on agricultural water management sector for crop growing season were analyzed by estimating the temporal trend in winter minimum daily temperature and FFDs on a monthly timescale over a 70 years period for Ontario Canada. The main objective of this study is to examine the temporal changes in Minimum Daily Temperature (MinDT) on a monthly and seasonal timescale and description of the relationship between the FFDs and extreme winter minimum daily temperature (WMinDT) across the Ontario, Canada.
2. STUDY AREA AND DATA SOURCES

2.1 Study Area

In this study, stations were selected in southern Ontario, Canada to describe the
temporal daily temperature trend. The four stations used in this study are shown in
Figure 1. These selected four station are Sault Ste. Mari, Sudbury, Ottawa and
Fergus.

![Figure 1. Study area map with location of selected four stations across Southern Ontario.](image)

The southern Ontario region has warm summer with normal thunderstorm activities.
In this region of Canada, May to September months are affected with severe storms
viz., high damaging wind, hail and tornadoes etc. The Windsor to London corridor
affected by such type of weather events. London experiences approximately 30% more
snowfall than Windsor, because of its relative location to Lake Huron and the
resulting snowbelt in Middlesex county.

2.2 Data Sources and Collection

In this study, FFDs and WMinDT are assessed as a function of MinDT. The climate
variable used in this analysis is the MinDT, or in other words the lowest recorded
temperature in a day. This data is available for many Canadian locations from
Environment Canada’s National Climate Data and Information Archive. The available
length of data for this study was 70 years (1940 to 2010), sufficient for long-term
trend analysis. However, in this analysis all the winter months (November to April)
datasets were included. Reason of selecting winter period data are: a) More rain in
winter season is increasing; b) Snow is decreasing in winter period and C) Occurrence of streamflow in early spring and late winter.. Since the data analysis
were done to examine temporal trend in temperatures time series on monthly basis,
the data was arranged in a chronological fashion, but with each month separated
from each other.

3. MATERIAL AND METHODS

3.1 Method used to Analyse the Minimum Daily Temperatures (MinDT) and
Frequency of Frost-Free Days (FFDs)

Once the data was arranged in appropriate manner, the mean monthly minimum daily
temperature was determined for each month for each year. For example, the mean
MinDT of January 1940 was calculated, then the mean of January 1950, repeated for
all months for all years. To analyse the trend in MinDT the linear trend line function
was fitted to the data. The trend line generally showed an increasing or decreasing
trend at a steady rate. A linear trendline equation used to calculate the least square fit for a line was:

\[ y = m \times x + c \] ……………………. (1)

Where, \( m \) is the gradient or slope of the line, and \( c \) is the intercept, the \( y \) is constant, when \( x=0 \).

3.2 Relationship between Frost Free Days (FFDs) and Mean Winter Minimum Daily Temperature (WMindT)

The correlation between the number of FFDs per month and the mean WMinDT of that month was explored to develop a possible relationship between these two variables. The decadal averages of the number of FFDs per month were plotted verses the decadal averages of the winter minimum monthly daily temperatures, and a linear regression was computed for each station. This analysis was repeated for selected stations across Ontario, Canada. These stations were then placed together, with similar latitude and geographic location and these data points were placed together on a single scatter plot. The FFDs and mean WMinDT data of months were arranged in decades from 1940 to 2010 for each of the stations. A defined relationship was estimated through these data points using the non-linear regression function in Minitab. Hence, the ‘number of FFDs per month’ were averaged together to give an average number of FFDs per month per decade and a linear regression was computed for selected station.

4. RESULTS AND DISCUSSION

4.1 Long-term Temporal Trend Analysis of Monthly Mean Minimum Daily Temperature (MinDT) for a Period of 1940 to 2010.

This section examines characteristics of minimum and maximum daily temperature datasets over a period of 70 year in southern Ontario, Canada. The mean monthly diurnal temperature range (DTR) is defined as the difference between the mean monthly maximum and minimum temperatures. Hence, the comparison of mean maximum, minimum daily temperatures and DTR are represented in Figure 2. These data show daily temperature trend over 70 years for four selected stations (a) Fergus Shand Dam, (b) Ottawa, (c) Sault Ste. Marie and (d) Sudbury. For the Fergus Shand Dam station, the mean MinDT shows an increasing trend, about an average of 2.7 °C during non-growing season (Nov to April). During the month of December, the mean MinDT has increased by 4 °C but throughout growing season the mean MinDT is about 2 °C. However, for the same station, mean Maximum Daily Temperature (MaxDT) shows an increasing trend for the month of March (2.8 °C) and maximum DTR is found to be during the month of October. The Ottawa station (in the eastern region of Ontario) follows the increasing trend similar to Fergus Shand Dam for MinDT. The average increase in MaxDT was 1.3 °C and DTR decreased by 0.94 °C for all the month. Sault Ste. Marie station (in the northern Agricultural region) also showed a increasing trend of MinDT during non-growing season with a significance level 0.1. The month of February showed a rise of 4.8 °C over 70 years period. The MaxDT and DTR at this station followed the trend similar to Fergus Shand Dam station (Figure 2c). Sudbury station also followed similar MinDT trend in growing season as other stations in southern Ontario. An average MinDT increased by 2.1 °C during non-growing season. The MaxDT and DTR also showed an increasing trend, by about an average of 2.1 °C and 0.5 °C, respectively (Figure 2d).
Figure 2. Long-term temporal trend of mean Maximum and Minimum daily temperature with their range over a period of 70 years at a Fergus Shand Dam, Ottawa, Sault Ste. Marie and Sudbury, Ontario, Canada.
4.2 Decadal Analysis of Relationship between mean Number of Frost-Free Days (FFDs) and mean Winter Minimum Daily Temperature (Wmindt) Across Ontario

On decadal basis average monthly number of FFDs was plotted against WMinDT to develop a possible relationship. The number of FFDs per month was put on as scatter plot with respect to x-axis time series. To develop a more accurate relationship between these variables, four stations of Ontario were plotted together in a way of logistic curve (sigmoidal curve) with their respective datasets (Figure 3). However, this analysis indicates a very clear relationship between of exponential growth (increasing more rapidly) of FFDs and mean WMinDT up until 0°C. Figure 3 illustrates the relationship between FFDs and mean WMinDT for selected four stations in Ontario (Ottawa, Toronto, Windsor and Woodstock) with a significant increasing trend in FFDs over winter months of each decade from 1940 to 2010. The result of all the stations display that the FFD are increasing with an increase in mean WMinDT. In addition, Table 1 represents regional increase in FFDs over winter during 100 year of period.

Table 1. Increase in number of frost-free days (FFDs) over 100 years in Ontario

<table>
<thead>
<tr>
<th>S. No</th>
<th>Region</th>
<th>Number of Stations</th>
<th>Increase in FFDs/100 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Southern Ontario</td>
<td>4</td>
<td>30-70</td>
</tr>
<tr>
<td>2</td>
<td>Central Ontario</td>
<td>3</td>
<td>10-40</td>
</tr>
<tr>
<td>3</td>
<td>Northern Ontario</td>
<td>5</td>
<td>0-15</td>
</tr>
</tbody>
</table>

Generally, as the latitude increases, the temperature will decrease, and the months will slide down along the logistic curve while keeping the same curve shape. The intervals for each station demonstrate the robustness of the relationships, and the fact that latitude and geographic location influence the shape of the relationship. The curve varies in different shape for selected stations. This difference is particularly visible between -10°C and 0°C (Figure 3). Therefore, overall it was observed that an increase of FFDs is more in Windsor (Southern region) compared to Ottawa (Eastern region).

Figure 3. Linear regression between mean numbers of FFDs and mean of winter minimum daily temperature for selected stations across Ontario, Canada.
5. CONCLUSIONS

In this study, the temporal trend is observed in the mean winter Minimum Daily Temperature and the number of Frost-Free Days (FFDs) across Ontario Canada. However, it is observed that the mean minimum daily temperature in agricultural region of Ontario has increased by about 2°C during non-growing (Winter) season over 70 years period. The increase in extreme daily minimum temperature is almost twice than the increase in mean minimum daily temperature. The results also indicate that the number of FFDs over winter period have increased exponentially when mean winter minimum daily temperatures rise progressively. This results in the increase in the length of growing season. It is also resulting in a decrease in snowfall and increase in rainfall during non-growing season. Also, this outcome effects the hydrological regimes including groundwater recharge and direct runoff and base flow components of stream flow. Further it is also impacting the soil erosion and sediment loads in the streams.

6. ACKNOWLEDGMENTS

The authors are thankful to the University of Guelph (UG), Ontario, Canada for providing financial support during the study period

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ASSESSMENT OF CLIMATE CHANGE IMPACTS AND ADAPTATION MEASURES TO MALWATU OYA RIVER BASIN IN NORTH CENTRAL PROVINCE OF SRI LANKA

T J Meegastenna¹

ABSTRACT

The impacts of global warming and climate change are now a reality in the world and its effects are being felt all over the world. Sri Lanka has also experienced the increasing frequency of catastrophic weather events such as cyclones, prolonged droughts and high intensity rainfall same as other countries. The impact of floods and droughts causes a severe damage and incurs a heavy cost to the Sri Lankan government amounting to millions of rupees for relief almost every year. In addition, loss of life, property, social unrest and maintain food security are associated problems from the impacts.

Malwatu Oya basin is the Second largest basin and is located in the dry zone of mid Northern Sri Lanka. The main river is 164 km long connecting the ancient city of Anuradhapura with the coast at Mannar city. The basin possesses large number of reservoirs from small sized village tanks to comparatively large reservoirs. This basin consists of a large number of water bodies, paddy cultivation areas and forest lands. Agriculture in this basin depends entirely on Northeast monsoon rainfall. Tank based farming systems have been in practice since ancient times remains the primary agricultural practice today.


For assessment of climate change on the water resources and impacts of flooding and drought Climate change scenarios are being developed for a base line and three future climate change scenarios such as optimistic, pessimistic and average for the future 2040. The main objective of this paper is to discuss the results of the climate change impact assessment and adaptation measures to reduce future impacts.

Keywords: Floods, Droughts, impacts, irrigated agriculture

1. INTRODUCTION

Malwatu Oya basin lies within the North Central, Northern and Central province in Sri Lanka. It has a catchment area of 3,187 Km² and Main River is 164 km long connecting ancient city of Anuradhapura with the coast at Mannar. (Figure 1) The basin is the second largest in Sri Lanka, and it is unique with its large number of small reservoirs (1450), ranging from small-sized village tanks to larger reservoirs. The upper basin of Malwatu Oya is fairly well developed with large reservoirs, paddy lands and several minor irrigation works.

The total population in the basin is around 410,000 as per the 2012 census with majority of people in Anuradhapura district. The population is expected to increase to about 716,000 by 2040.

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The basin is flood and drought prone while significantly damaging flooding occurs, associated with the city of Anuradhapura. Historically, the Malwathu Oya basin has been subjected to droughts, mainly caused by unusually long dry seasons or late onset of the monsoon. Water shortages are considered as a main issue for all three districts in this basin. The majority of the basin is a mosaic of paddy, water body (reservoirs and lakes for water storage for dry season irrigation), garden, grassland, scrub and forest. This basin is a classic example of dry zone irrigated agriculture which is described as a three-fold land use system comprising irrigated rice fields, home gardens and chena (upland) cultivation.

![Figure 1: Malwatu Oya Basin (showing District boundaries, main water bodies and transport network)](image)

Source [1]

The main land use change is the historical conversion of lowland forest to agriculture and regrowth vegetation by shifting cultivation, and the subsequent conversion to commercial agriculture. The main land use issues are related to the relatively heavy use of agrochemicals and the potential for nutrient accumulation, and the lowering of the water table by dry season extraction. This results in water shortages in the Yala season and inland salinization.

The main source for water supply in Malwathu Oya basin is groundwater. As per the 2011 census, around 75% of people depend on groundwater from dug wells and tube wells. National Water Supply and Drainage Board (NWSDB) and Community Based Water Supply schemes cover around 27% of community in this basin. Around 180,000 m³/day water is being extracted from reservoirs to supply water to Anuradhapura city.

A number of issues related to water supply have been reported, including contamination of surface and groundwater due to overuse of agrochemicals and fertilizer, increasing demand due to urbanization of main town and suburbs, and overexploitation of groundwater from both shallow and deep wells.

As part of the irrigation system in this basin, agro wells are used to pump water during the dry season. Apart from these, dug wells are used to extract water for domestic purposes.
The prevalence of abandoned paddy land is high in the basin and is due to water shortage and/or infilling of tanks. The outcome of the abandonment of paddy land is a decrease in the attenuation of water within the basins resulting in increased incidence of waterlogging and flooding. In addition to abandoned paddy ‘one season paddy’ land occurs mainly in Mannar and Vavuniya districts and refers to the increasing incidence of drought resulting in the abandonment of tanks, degradation of distribution systems and an increase of ‘one season paddy’ both rain-fed and irrigated. Not all areas of one season paddy are due to tank abandonment, some areas have never been irrigated but the extent has grown in recent years both as a result of the war and drought. The outcome of an increase in one season paddy is only felt locally but will be a decrease in the attenuation of water with greater runoff in periods of heavy rain increasing localized waterlogging and flooding. The outcome is a lower annual cropping intensity, lower yields and increased crop insecurity.

2. CLIMATE AND HYDROLOGY

The Malwathu Oya basin lies within the dry climatic zone of Sri Lanka. Average temperature is 28°C and annual average rainfall is about 1,300 mm. Anuradhapura district is usually hot and humid throughout the year with April being the hottest month of the year with temperatures reaching 34°C. January is the coldest month of the year with minimum temperatures of 21°C.

Malwathu Oya basin is located in flat terrain and the basin boundary is not well defined in terms of visible watersheds other than at the Inamaluwa mountain range at the southern boundary of the upper basin. The Malwathu Oya basin has a river gauge at Kappachchi. However it has a poor period of record and was nonoperational for some 20 years due security reasons. There are a number of manmade reservoirs (under major, medium and minor categories) that have been built to manage the water stress situations and assist with irrigation water supply. These are located throughout the Malwatu Oya basin and available in the upstream of Anuradhapura. (See Figure 2 for schematic diagram of major and minor reservoirs)

![Figure 2: Schematic diagram of Malwatu Oya Basin](image)

The upper catchment of the Malwathu Oya basin contains five major reservoirs: Nachchaduwa (originally built in 998 AD), Mahakanadarawa, PavatKulam, Nuwarawewa and Tissa Wewa. Nachchaduwa Reservoir receives inflows diverted from Mahaweli basin. During the flood of May 2016, these inflows were blamed as being part of the problem when Nachchaduwa spilled and flooding occurred in Anuradhapura town.
Thekkam Anicut (barrage) is located about 36 km upstream of the sea coast and augments reservoirs located in the adjacent coastal basins, mainly Giant’s Tank and Akitamuruppu tanks on the right bank and left bank respectively. The Malwathu Oya basin is augmented by the adjacent Kala Oya basin from the Kala Wewa Reservoir via Yoda Ela to provide water to Nachchaduwa, Tissa Wewa and Basawakkulama.

3. **CLIMATE CHANGE IN SRI LANKA**

Rainfall in Sri Lanka has multiple origins. Monsoonal and convectional rainfall, and the formation of synoptic weather especially in the Bay of Bengal, account for the majority of the annual rainfall. The average annual rainfall of the island varies from about 900 mm at the southeastern part of the Dry Zone to over 5,500 mm month south-western slopes of the Central Highlands [2]. The rainfall experienced during a 12-month period in Sri Lanka can be characterized into four rainfall seasons, namely, first inter-monsoon (March–April; FIM), southwest monsoon (May–September; SWM), second inter-monsoon (October–November; SIM), and northeast monsoon (December–February; NEM). Sri Lanka possesses a long series of historical climatic data, especially rainfall and temperature records, which started from the 1860s in some locations. A recent analysis of these data has shown that the country’s average temperature is significantly increasing at a rate of 0.01–0.03 °C per year [3]. The increase is more pronounced in night time minimum temperature than that of the daytime maximum temperature [4].

However, due to high inter-annual variability, there are no discernible significant trends in seasonal and annual rainfall [4], except a few locations among over 400 rain gauging stations of the country as has been found in many other locations across the globe. The same is true in terms of variability of cumulative and seasonal rainfall. However, it was evident that variability of seasonal rainfall during the most recent decade (2001–2010) has increased compared to the previous decade (1991–2000) in most places of the island across all three climatic zones (Wet, Dry and intermediate) with occurrence of more frequent drought and flood conditions [4]. North-east monsoon rainfall anomaly is negative for short term (2020 – 2040), medium term and long term projections and negative trend is observed under moderate emission scenario Representative Concentration Pathways (RCP) 4.5 and Second Inter Monsoon rainfall anomaly is negative in Northeastern parts, and positive in Southwestern parts in 2020-2040 [5].

4. **FLOOD AND DROUGHT RISK ANALYSIS IN SRI LANKA**

Climate-related hazards pose a significant threat to economic and social development in Sri Lanka. Extreme variability of rainfall and droughts is already a defining feature of Sri Lanka’s climate. Climate projections indicate an increasing rainfall trend in the wet zone and a decreasing rainfall trend in the dry zone, meaning that the risks associated with water-related hazards are likely to increase [6]. Annual average fiscal loss associated with disasters is estimated to be already more than US$380 million, but disaster losses can significantly exceed this amount in each year. In 2011, floods affected more than a million people in the Northern, North Central and Eastern provinces and caused more than US$600 million in direct damages. Floods in 2012 affected nearly a half a million people and the December 2014 floods affected 1.2 million people.

Each of these events severely impacted the agriculture sector, destroying crops, livestock and agricultural infrastructure, and the road infrastructure. The floods and landslides of December 2014 affected 22 out of the 25 districts in the country, killed 39 people and damaged more than 25,000 houses. The rapid damage assessment conducted by the National Planning Department (NPD) revealed that direct damages
to public assets were US$ 155 million, including an estimated damage of US$ 65.4 million to irrigation and flood control infrastructure and an estimated damage of US$ 85 million to the road infrastructure. Provincial roads suffered the most of the damages, especially in Uva Province, amounting to US$ 70.6 million.

5. FLOODING IN THE MALWATU OYA BASIN

Flood history in this basin goes back to 1919 with recorded water levels at Thekkam Anicut. According to records, there were floods in Malwathu Oya basin in 1919, 1922, 1923, 1957, 1979, 2011, 2012 and 2014. Though water levels during some of these floods are available at Thekkam anicut (Figure 3), they were not classified into minor, medium, and major/critical.

The 1957 flood is the worst flood during the last century, and the flood that occurred in December 2014 is considered the worst since 1957. During the 2014 flood (Figure 4), major tanks located upstream of Anuradhapura were full and the opening of flood gates was required. Embankments of some of the small tanks were also breached resulting submerging villages in downstream and parts of Anuradhapura City.

6. DROUGHT IN THE MALWATU OYA BASIN

Malwathu Oya basin has been subjected to droughts too, mainly caused by unusually long dry seasons or late onset of the monsoon. Such events were recorded in 1947/48, 1952/53, 1955/56, 1972/73, 1978/79 2003/04, 2012, 2014, and 2016. Water shortages are considered a main issue for all three districts in the basin. In addition to these more severe droughts, water shortages are reported almost every year.
7. FLOOD AND DROUGHT RISK ANALYSIS IN THE MALWATU OYA BASIN

The economic cost of climate change in the Malwathu Oya basin has been evaluated through the calculation of Annual Average Damage (AAD). The damage values for the categories of economic assets, such as public infrastructure (roads, railways, flood embankments), agriculture, building fabric, building contents and vehicles. The flood hazard maps provide a powerful tool to assess the current and future risk of flooding and should be used to support strategic policy decisions for prioritizing investment.

The flood risk economics have summarized and the following conclusions can be made from the assessment.

1. For the current situation, (Case 1) the overall flood risk economic impact in any given year (AAD) is estimated to total USD 8.6 million. This clearly indicates that, without flood mitigation measures, major damages and losses are expected to be incurred in the basin under the current climate situation and present level of basin development.

2. Under the climate change scenarios without basin development, the pessimistic climate change scenario (Case 2) is anticipated to result in greater damages with an increase in the AAD value to USD 10.8 million. Furthermore, for the average (Case 3) and optimistic (Case 4) climate change scenarios, AAD values were estimated at USD 10.2 million and USD 8.7 million, respectively.

3. Under the climate change scenarios with basin development, the pessimistic climate change scenario coupled with future basin development (Case 5) is expected to result in an increase in the economic value of AAD from USD 9.3 million to USD 11.6 million.

Above flood risk economics provide strong evidence of flood damages (summarized in Figure 5) and therefore the benefits of investing in flood mitigation. There is a strong correlation between land use change and the associated increase in both population and urban areas with increase in flood damages. To expand on this point, the impacts of climate change from flood risk are exacerbated by population increases and land use change. In addition future urban development in towns and along transport corridors within the basin will increase asset values and consequently the economic damages suffered during future flood events. These conclusions highlight that the earlier the investment in flood risk mitigation the greater the economic benefits. It is logistically easier to develop flood defenses while the areas remain predominantly rural than when they become higher density urban environments.

The economic cost of drought risk due to climate change in the Malwathu Oya basin has been evaluated through the calculation of AAD for domestic and non-domestic public water supply, minor and major/medium irrigation agriculture, and rain-fed agriculture. The AAD was considered the magnitude of demand deficits (i.e. unmet demand) in the basin.

Further to the AAD calculation, the drought risk assessment has also considered the impact of climate change and basin development on sectors through an evaluation of predicted changes in environmental flow risk and recharge to groundwater.

A set of drought hazard maps provide a powerful tool to assess the current and future risk of drought and could be used to support strategic policy decisions for prioritizing investment.
The drought risk economics have summarized and the following conclusions can be made from the assessment.

1. The total drought risk AAD under current situation in the Malwathu Oya basin has been estimated as USD 48 million. This figure is dominated by impacts on minor irrigated agriculture.

2. Drought risk AAD has been estimated to increase by approximately LKR 1.8 billion (USD 12 million) up to USD 60 million under the pessimistic climate change without basin development scenario (Case 2), and reduce by approximately USD 13.1 million to USD 35 million under the optimistic climate change without basin development scenario (Case 7).

The increase in drought-related losses associated with pessimistic climate change without basin development is dominated by a predicted increase in drought-related losses associated with minor irrigated agriculture. Relative reductions in drought related losses associated with the basin development scenarios (Cases 5 to 7) are driven by a coupled effect of future infrastructure developments, providing more drought resilience (Figure 6) and a reduction in rain-fed agriculture areas due to land use change.

**Figure 5 & Figure 6**: Flood Risk Annual Average Damage & Drought Risk Annual Average Damage under basin condition and climate change scenario

Source [7]

8. Combined Flood and Drought Economic Damages for Malwathu Basin

**Table 1**: Combined flood and drought economic damages for Malwathu basin

<table>
<thead>
<tr>
<th>Case</th>
<th>Climate Condition</th>
<th>Basin Condition</th>
<th>Flood Risk Annual Average Damage USD M</th>
<th>Drought Risk Annual Average Damage USD M</th>
<th>Total Annual Average Damage USD M</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>current</td>
<td>current</td>
<td>8.6</td>
<td>48</td>
<td>56.6</td>
</tr>
<tr>
<td>2</td>
<td>2040 – Pessimistic</td>
<td>current</td>
<td>10.8</td>
<td>60</td>
<td>90.8</td>
</tr>
<tr>
<td>3</td>
<td>2040 - Average</td>
<td>current</td>
<td>10.2</td>
<td>53</td>
<td>63.2</td>
</tr>
<tr>
<td>4</td>
<td>2040 - Optimistic</td>
<td>current</td>
<td>8.7</td>
<td>42</td>
<td>50.7</td>
</tr>
<tr>
<td>5</td>
<td>2040 - Pessimistic</td>
<td>2014 with planned development</td>
<td>11.6</td>
<td>49</td>
<td>60.6</td>
</tr>
<tr>
<td>6</td>
<td>2040 - Average</td>
<td>2014 with planned development</td>
<td>10.8</td>
<td>43</td>
<td>53.8</td>
</tr>
<tr>
<td>7</td>
<td>2040 - Optimistic</td>
<td>2014 with planned development</td>
<td>9.3</td>
<td>35</td>
<td>44.3</td>
</tr>
</tbody>
</table>

Source [7]
9. PROPOSED INTERVENTIONS

The Malwathu Oya basin is hydraulically complex during flood events due to the influence of its four major reservoirs in the upper basin (Nachchaduwa, Mahakanadarawa, Nuwarawewa and Tissa Wewa) and large number of minor and medium reservoirs, along with a number of interconnecting canals between the reservoirs in addition to the main watercourses.

A large number of interventions were proposed during the stakeholder consultation workshops. Most suitable interventions have been investigated to select the most appropriate interventions as below to mitigate flood impacts in upper basin.

1. Nachchaduwa Reservoir – It has been proved that Nachchaduwa reservoir is very important reservoir in terms of flood mitigation for Anuradhapura City. Following interventions have been investigated with the association of Nachchaduwa Reservoir as described below.
   a. Increased spill gates discharge capacity into the Malwathu Oya. Intervention comprises the replacement of the existing hydraulic gates with larger gates (wider and deeper gates with lower sill levels) to maximize the potential to drawdown Nachchaduwa Reservoir prior to flood event
   b. Operational regime changes to include drawing down reservoir levels prior to large rainfall / storm events. This will generate additional volume to be used to attenuate flows – resulting in a reduction in the risk of uncontrolled spill into the Malwathu Oya during a flood event.

2. Construction of new reservoir with a 209 MCM at the middle basin, below the Anuradhapura town to mitigate impact of the flood and drought at lower Malwathu Oya basin. It will be beneficial to increase cropping intensity of lower basin irrigation schemes (Giants tank and Akathiemuruppu), and ensure the drinking water facilities around the areas and lower basin.

3. Improving conveyance through bridge / causeway structures.

4. Introducing new flood embankments at the both side of Malwathu Oya to protect Anuradhapura city.

5. Increasing storage capacity of upper basin medium and minor reservoirs to reduce impact of drought.

10. CONCLUSIONS

Nachchaduwa Reservoir, and its operations, is the key to flood mitigation for Anuradhapura City. Further variations of drawdown and outlet gate enlargements can be tested at feasibility stage and an optimization based on costs and benefits completed to determine the final configuration. This intervention is technically and economically viable, and also the environmental and social impacts are low. Nachchaduwa reservoir operations can be further improved with the accurate quantitate rainfall forecast and then, develop the reservoir operation rule curves. It is also recommended that development of an early warning system with hydro-meteorological and river level gauges is considered.

Intervention 2 is technically, and economically feasible, and its environmental and social impacts are moderate. Intervention 3 and intervention 4 are technically, and economically feasible, and there environmental and social impacts are
low. Intervention 5 [4] is technically feasible only to mitigate drought and is not economically feasible. Furthermore, its impacts on environment and social are moderate.

11. REFERENCES

STRATEGIC ACTION PLAN TO COMBAT CLIMATE CHANGE IMPACT IN IRRIGATION SECTOR IN SRI LANKA

S M D L K De Alwis

ABSTRACT

Irrigation and Water Resources Management is vital for economic development and social wellbeing of Sri Lanka. Being an Island having a tropical climate, Sri Lanka is highly vulnerable to climate change impacts and already experiencing extreme weather events resulting in water scarcity, which is now becoming a common occurrence. In recent times, water demand for domestic and industrial sectors has increased due to recent changes in economic policies and social conditions. Considering the low cropping intensities and low water productivity in irrigation systems, there is an unmet demand for agriculture as well. In addition, rain fed paddy cultivation is gradually becoming vulnerable to climate change impacts.

According to climatologists, the trend analysis of temperature reveals that both day time maximum and night time minimum temperatures are increasing significantly at a rate of 0.01 – 0.03 °C with a few exceptions. Sea water level rise is still not estimated but is noticed resulting in sea water intrusion into the lands that reduces the cultivatable area. Though the annual average rainfall has remained unchanged in different climatic regions in the country, considerable change in rainfall intensities is becoming a serious issue for meeting the water demand across all sectors.

Increasing frequency of floods and drought is also becoming an area of concern. The National Climate Change Adaptation Strategy (NCCAS) introduced a Strategic Action Plan to combat climate change impacts in irrigation sector, which includes nine strategies with appropriate new technology and mainstreaming management plans explicitly to implement from 2019 to 2025 and beyond. This paper discusses Sri Lanka specific?country-wide? issues on climate change impacts and strategic action plan introduced to combat them.

Keywords: Climate change, Vulnerable, Irrigation Productivity, combat, Strategies, technology, Sri Lanka

1. INTRODUCTION

Sri Lanka has a tropical climate with distinct dry and wet seasons. The country exhibits a very diverse terrain resulting in many climatic zones which result in high bio-diversity across the islands’ small landmass of approximately 65,610 km². There are 103 distinct natural river basins and over 90 small coastal basins (Arumugam, 1969). Water bodies cover about 2,905 km² (CBSL, 2007) and a considerable portion of these water bodies consist of manmade reservoirs. These reservoirs capture part of the surface runoff for different kinds of uses - specially for irrigated agriculture which supports fulfillment of the nation’s food security. The paddy land includes both irrigated and rainfed lands. The extent under paddy cultivation covers 625,000 ha of irrigated lands and 219,000 ha of fed lands that covers a total of 12.90% of total land area (ADD reference please).
The average annual rainfall over the country is approximately 1850 mm generating an estimated volume 12x10$^{10}$ m$^3$ of water, about a third of which comprises the annual surface flow to the ocean (Sri Lanka Water Development Report, 2010). Internal renewable annual water resources of Sri Lanka is estimated as 52.80 km$^3$ approximately (Aqua stat-FAO, 2017). Present per capita water availability is 2,150 m$^3$ per year. Water withdrawal for irrigation in Sri Lanka in 2005 was estimated at 11,314 million m$^3$. Considering the irrigation development since 2005, the current withdrawals are estimated to be 12,000 million m$^3$.

The tropical geographical location of Sri Lanka ensures uniformly high temperatures throughout the year, but influence of the surrounding ocean makes the island free from the temperature extremes.

Anticipated climate change in response to enhance greenhouse effects is expected to cause shifts in frequency and magnitude of sporadic extreme weather events along with a slow but steady rise in surface temperature (Add REF). On the other hand, demand for water in different sectors such as agriculture, domestic, industry, energy etc. are on the increase. Persistent climate change is likely to make meeting these challenges of water management increasingly difficult. Extreme weather events such as high intensity rainfall followed by flash floods, landslides and prolonged drought periods resulting water scarcity and adverse impact to the economy are now becoming common occurrences in Sri Lanka.

The government introduced a Strategic Action Plan to combat climate change impacts in irrigation sector, which includes nine strategies and management plans to implement from 2019 to 2025 and beyond. This paper discusses country specific issues of impacts of climate change and the strategic action plan introduced to combat them.

2. PROJECTED CHANGES IN WEATHER AND CLIMATE IN SRI LANKA

Local climatologists show that temperatures are projected to increase in the medium to long-term in North and North Central Provinces (Figure 1). A study using HADCM3 found that average annual temperature is predicted to increase by 1.6°C and 1.2°C under the A2 and B2 SRES scenarios respectively (Add Ref).

Rainfall modelling always presents a more complex scenario than projected temperature increases, but generally indicate that the wetter areas will decline and that large areas of the Dry Zone will receive less rainfall in the medium term (2015-2025) (Add REF). A study carried out using HADCM3 showed that South West Monsoon (SWM) rains could increase by 38% (SRES A2 scenario) and 16% (B2 scenario) in the 2050s. The North East Monsoon rainfall, which provides the major part of rainfall to Dry Zone, was projected to decrease by 34% and 26% under the same scenarios respectively (Ref).

Furthermore, a simple daily intensity index, defined as the annual total rainfall divided by the number of wet days, indicated a positive trend in the Dry Zone, although the trends were not statistically significant (Ref). In comparison, a more recent study published in 2017 using a multi-model ensemble shows that annual averaged mean minimum and maximum temperatures increase in short-term (2020-40), medium term (2040-70) and long-term (2070-90) (Ref). This is evident in both low-emission and high-emission scenarios. The projections for precipitation are shown in Table 1. (Jayawardane et al., 2017).
Table 1. Summary of projections for precipitation under different scenarios (Jayawardane et al., 2017) remove space before & after lines & optimise table.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Emission scenario</th>
<th>2020-2040</th>
<th>2040-2060</th>
<th>2060-2080</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual rainfall anomaly</td>
<td>RCP 4.5</td>
<td>Negative in north-eastern parts positive in southwestern parts</td>
<td>Positive and increasing</td>
<td>Positive and increasing</td>
</tr>
<tr>
<td></td>
<td>RCP 8.5</td>
<td>Positive and increasing with significant increase in the Wet Zone</td>
<td>Positive and increasing, significant in the Wet Zone</td>
<td>Positive and increasing</td>
</tr>
<tr>
<td>Southwest monsoon rainfall anomaly</td>
<td>RCP 4.5</td>
<td>Positive and increasing, significant in the Wet Zone</td>
<td>Positive and increasing, significant in the Wet Zone</td>
<td>Positive and increasing, significant in the Wet Zone</td>
</tr>
<tr>
<td></td>
<td>RCP 8.5</td>
<td>Positive and increasing, significant in the Wet Zone</td>
<td>Positive and increasing, significant in the Wet Zone</td>
<td>Positive and increasing, significant in the Wet Zone</td>
</tr>
<tr>
<td>Northeast Monsoon</td>
<td>RCP 4.5</td>
<td>Negative</td>
<td>Negative</td>
<td>Negative, significant in the Dry Zone</td>
</tr>
<tr>
<td></td>
<td>RCP 8.5</td>
<td>Slightly positive</td>
<td>Negative</td>
<td>Negative, Significant in the Dry Zone</td>
</tr>
<tr>
<td>First Inter-Monsoon</td>
<td>RCP 4.5</td>
<td>Negative</td>
<td>Slightly negative</td>
<td>Positive except north-east</td>
</tr>
<tr>
<td></td>
<td>RCP 8.5</td>
<td>Negative</td>
<td>Negative</td>
<td>Negative</td>
</tr>
<tr>
<td>Second Inter-Monsoon</td>
<td>RCP 4.5</td>
<td>Negative in NE and positive in southwestern parts</td>
<td>Positive</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td>RCP 8.5</td>
<td>Positive and increasing, significant in southeastern and southwestern parts</td>
<td>Positive and increasing</td>
<td>Positive and increasing</td>
</tr>
</tbody>
</table>

According to another study conducted by national climatologists it has been proven that average temperature in dry and intermediate zone will increased gradually and the situation may become worst affecting the irrigated agriculture sector in Sri Lanka by the end of 21st century (MUST give REF). Increasing evaporative demand results in high water consumption of food crops leading to challenges in reservoir water management and system water management. Figures 1 and 2 show the projected temperature and rainfall changes over Sri Lanka (Punyawardane et al., 2010).

Land size MUST be the same in both figures & need more detail in Legends

Figure 1. Long-term temperature changes for 3 future time intervals across Sri Lanka (REF)

Figure 2. Long-term rainfall changes for 3 future time intervals across Sri Lanka (REF)

Similarly, projected precipitation changes (Figure 2) show same threat in receiving rainfall to dry zone and wet zone with resultant negative impact on irrigation and agriculture sector. This study revealed and generally agree on some important
aspects of the predicted climate. One important conclusion is that the north-eastern, eastern and south-eastern parts of the country are more likely to be high-water-demand regions. In addition to that studies carried out by the Climate Change Secretariat of Sri Lanka also proved the above statement (REF). Results have been published in the sectorwise Climate Change Vulnerability Data Book (Sri Lanka Ministry of Environment, 2011). Fig. 3 and Fig. 4 reflects the irrigation sector vulnerability due to drought and heat stress and Rice sector vulnerability due to drought respectively confirming the above-mentioned study outcomes.

![Figure 3. Irrigation sector vulnerability due to drought and heat stresses (Ref)](image)

![Figure 4. Paddy rice sector vulnerability due to drought (ref)](image)

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3. SUMMARY OF LIKELY IMPACTS OF CLIMATE CHANGE ON WHAT?

Summarizing the projections and observations, water resources management in Sri Lanka is most likely to confront the unpredictable weather patterns (Jayawardane et al., 2017; De Silva et al., 2007). Prolonged dry periods, high temperatures leading to high evaporation and evapotranspiration losses are more prominent as adverse impacts.

Likely impacts on life and livelihoods include:

i. Decreasing production in farm fields due to decreased water storage capacity, and high levels of evaporation from village reservoirs and increased crop losses due to longer periods of drought.

ii. Decreased availability of year-round safe drinking water due to longer droughts, declining water quality and lack of adequate water storage facilities.

iii. Loss of life, damage to livelihood assets including livestock and community assets such as village irrigation infrastructure.

A reasonable estimate of irrigation requirements, for the major users, is assessed at 3% higher than the current requirement. Accordingly, additional water requirements for irrigation in 2025 is likely to be in the range of 350-450 million m$^3$. This is based on the impacts of climate change only without taking into accord any increase in irrigated areas. In addition, changing temperatures and rainfall can affect crop yields. However, as that impact is beyond the scope of this strategic action plan, the subject is not dealt with here.
4. ADAPTATION STRATEGY - A RIVER BASIN APPROACH

Several water resources management problems are linked to inadequate plans for environmental management and not addressing predicted climate change impacts. Deterioration of the watersheds and unplanned development within the watersheds has resulted in sedimentation of reservoirs, flash floods, and inadequate groundwater recharge (ref). Land degradation has resulted in the loss of productivity (ref). As a result, climate resilience in both major and minor irrigation systems has been reduced.

In addition, this has resulted in threats to important ecosystems with loss of forest cover and loss of bio-diversity including coastal ecosystems and wetlands. Salt-water intrusion is a major problem in the coastal areas affecting both agriculture and drinking water supply (ref?).

An analysis of the trends of water resources management in Sri Lanka shows that there is a clear trend of adopting solutions based on river basins. Attempts made since 2005 (Ref) reflects the necessity of river basin based hydrological assessment including modeling, trans-basin diversion of water, either sub-watershed based or cascade-based irrigated agriculture development, water allocation for drinking, improvement of irrigation efficiency and institutional arrangements for IWRM (ref).

River basin planning will include prioritizing the river basins for management interventions, structural interventions that include identifying technically, economically and environmentally feasible inter-basin and intra-basin diversions, and modernizing the hydrological monitoring network. Rehabilitation and modernization of existing irrigation schemes are also taken into account by looking at the aspect of productivity enhancement of land and water. Apart from those, some biophysical solutions are also identified in agriculture modernization to address climate change impacts which are more useful to prepare basin development plans.

At a macro level, riverine management will focus on watershed management, management of water quality, sediment transportation and studying flood behaviour. Rainwater harvesting for direct use in farmlands as well as groundwater recharge need to be introduced appropriately.

5. STRATEGIC ACTION PLAN

5.1 Requirements of National Climate Change Adaptation Plan (NCCAP)

The government introduced National Climate Change Adaptation Plan (2016-2025) that identifies several priority actions for the identified sectors to meet the national requirements and global aspects of SDG too. The most relevant actions for irrigation and water resources are summarized below:

- Develop and implement watershed management and conservation plans for critical watershed areas.
- Increase the efficiency of water use and reduce losses in irrigation systems through better operation and maintenance (O&M), and climate-resilient water management practices.
- Identify and map areas vulnerable to drought and flood hazards, design rational intra-basin and trans-basin strategies to harness periodic surpluses of water; and prepare disaster risk management plans.
- Introduce climate-smart agriculture through capacity building of relevant sectors including adoption of agriculture modernization.
- Modify irrigation techniques and adopt water efficient technologies.
5.2 Strategic Action Plan for Climate Change Adaptation in Irrigation Sector

(a) Restore and rehabilitate all abandoned and working tanks and irrigation canals

Restoration and rehabilitation of abandoned tanks including irrigation canals will be done to increase the total storage capacities. Recent rehabilitation efforts have faced several barriers such as lack of a uniform criterion to select schemes, O&M methodologies, construction methods, de-silting, and quality control etc. As such, there is a need to modify and update the existing design guidelines that will incorporate the improved hydrological design standards (discussed above), construction standards and quality control guidelines, as well.

(b) Establish water flow and sediment load monitoring systems in selected streams

Deterioration of water quality observed in many rivers due to anthropogenic activities and natural hazards affect human health, hydropower generation, livelihoods environment and economy in general. Increased sediment and nutrient loading in rivers adversely affects the water quality. The pollutant concentration in rivers are correlated to river flows with the relationship varying spatially as well as temporally. Climate change further aggravates this problem. High intensity rainfall contributes to flooding, soil erosion, excessive sediment loads in rivers and sedimentation of reservoirs. Prolonged dry spells reduce ground water recharge and base flow in rivers, which contributes to increasing the pollution concentration.

As there are no systematic measurement of water quality at the river basin level, water flow and sediment loads monitoring systems are expected to be establish in selected river basins. Water quality measurements should be linked to the existing hydrological network. This will enable a better understanding of the relationships between river discharge and pollution levels.

(c) Introduction of boreholes / tube wells as a drought intervention for domestic water supply

Groundwater plays an important role in water resources management, in such areas as drinking water, irrigation, disaster management and industries. Until recently, groundwater's role was secondary to that of surface water. The nature and occurrence of groundwater have not been studied sufficiently well in the past. But recently a project was launched to study and estimate the groundwater potential by establishing a groundwater monitoring network at national level. The major activities in this recent study (Ref) include: groundwater monitoring, study of coastal aquifer system, hydro-geological studies and water quality studies. Although the aquifer boundaries differ from river basin boundaries, there is a need to assess and manage groundwater in a river basin context. As a preventive measure for providing drinking and agriculture water demands in water stressed areas, boreholes / tube wells will be introduced to relieve vulnerable socio-economic impacts due to climate change. Better knowledge of groundwater aquifers is also required to design borehole development and will be considered under this strategic plan.

(d) Enhancement of water use efficiency and water productivity

Water use efficiency is another important area of focus under the proposed strategic action plan, as more than 50% of the irrigation systems are operating at low irrigation efficiencies due to a variety of reasons. High labour cost and intensive labour requirements discourage farmers from maintaining standards in on-farm water and crop management practices. Reduced conveyance losses in irrigation networks will
be most important to increase the system-wide water use efficiency with lined canals in parallel with on-farm water management interventions, such as ‘Alternative Wetting and Drying’ (AWD) method for paddies and System Rice Intensification (SRI) method, along with other physical modifications through land consolidation to facilitate mechanization and water management.

(e) Assessment of floods and mitigation measures

Causes of dam and structural failures, consequences and magnitude of such failures are most critical areas under the structural interventions for climate change adaptation. Extremely high rainfall intensity can be expected that will contribute to flash floods, higher peak flows and increased risk of flooding that may cause dams to break or overflow. Sri Lanka has experiences of dam failures resulting in disastrous consequences. However, most of them were due to overtopping and few are due to structural failures. Other than the dam failures, a considerable amount of irrigation infrastructure also has failed during flooding. Except for recently constructed or modified large dams, many Sri Lankan dams were constructed with clear over-fall or Ogee-type spillways. New design methodologies include the use of radial gates, Labyrinth weirs, Piano Key weirs, fuse plugs, flap gates, bottom gates and combinations of the above. (Lamperiere et al., 2013). A few reservoirs in Sri Lanka are now equipped with such innovative designs and action will be taken to replicate the same for potential reservoirs, which need new design guidelines.

Breaching of a village tanks results in a disruption of vital functions, including providing basic water needs, livelihoods and environmental services as well as a “chain reaction” leading to a series of failures. Detailed hydrological analyses may not have been carried out in the original designs, when climate change was not considered a serious issue. Hence, there is a need to design them with more robust design methods. Therefore, modified hydrological design tools will be used under this strategic action with due consideration to climate change induced changes. Furthermore, introducing early warning systems in flood prone river basins will be introduced to mitigate and reduce impacts.

(f) Develop River Basin management plans

Water resources management under the changing climate will require a gathering of accurate data, producing useful information for managers and the community, and sharing and disseminating those in an efficient manner. In the planning process, this task has been treated in a sector wise approach by looking the magnitudes of climate change impacts on each sector. Detailed hydrological studies will be conducted and action will be taken to prepare water resource management plans incorporating the water resource development and conservation perspectives in river basin approach as described in chapter 4.

(g) Adopt water efficient technologies to harvest and conserve water

Soil moisture conservation and improving soil waterholding capacities in irrigable lands are other important aspect to address the climate resilience in irrigated agriculture. Low cost local technologies were available since early centuries of hydraulic civilization in Sri Lanka and are still valid for adaptation. However, these time-tested technologies were side-lined during the green revolution. Although new innovations and technologies were introduced by the agricultural extension officers, speedy actions have not yet been taken through capacity building of both farmers and officers.
Saltwater intrusion problems will be aggravated by the projected the sea level rise. Therefore, research is needed and development actions are proposed under the strategic action plan to safe guard the farming community in the coastal areas. Action will be taken to construct saltwater intrusion barriers adapting modern techniques.

(h) Modify irrigation techniques, including amount, timing or technology

Modernization of gravity irrigation systems require easy operational techniques to control and distribute water to the farms to fulfil the crop water demands. Downstream control gated structures are more appropriate to manage the water satisfactorily. Proper communication for implementing the water delivery schedules should be introduced in major irrigation systems and trans-basin diversion networks to reduce the management losses. Therefore, advance technological options to capture the canal discharge on a daily basis and communicate them in a timely fashion to the O&M staff and farmer organization leaders need to be introduced in order to improve water use efficiencies. Affordable micro-irrigation technologies will be promoted initially with innovative farmers. Adoption of micro-irrigation will require farmer acceptability, cost effectiveness and markets.

(i) Introduce conservation measures for irrigation tanks and canals to ensure sustainable water supply.

Conservation practices should be included in the areas of catchment management, reservoir management, main system management and sub-system management. Reservoir periphery management is effective in controlling soil erosion, sedimentation and water pollution. Regulation enforced for irrigation reservations protect the irrigation tanks and canal network but need continuous supervision. Legal frameworks need to be strengthened with required amendments to existing laws and regulations along with some policy reforms. Improvement of the lifetime of water infrastructure with better operation and maintenance (O&M) practices ensure the sustainable water supply in the irrigation system. Adequate funding for meeting O&M facilities will be a constraint for this task but Joint Irrigation Management (JIM) will be introduced at system level to reduce the burden of O&M managers. Programmes for raising O&M fund and mechanization of O&M work will be introduced and is already incorporated to the strategic action plan.

6. CONCLUSION AND RECOMMENDATIONS

According to the results of the studies done to assess climate change impacts of Sri Lanka, rainfall in South West Monsoon (SWM) in the Dry Zone will increase by 50-100 mm and North East Monsoon rainfall will decrease by 100 to 150 mm. It is extremely complex to estimate the changes in irrigation demand in the future, based on rainfall projections alone. Rainfall intensity is projected to increase in the future and that also will influence the amount of both surface and groundwater availability. Eventually, the water availability has to be calculated for individual river basins, taking different characteristics such as forest cover, land use, and topography into consideration.

The demand side is even more complex. While increasing temperatures are likely to increase evaporation and evapotranspiration, the increase in humidity associated with increased temperatures and increased CO₂ emission can result in a decrease in transpiration rates. Irrigation demand will be affected by the economic development, economic policies which are connected to food imports, and technology improvements such as micro-irrigation. Therefore, projected water demand and supply require a detailed analysis using state-of-the-art technology that will be done as a study under this Strategic Plan.
Considering the recent information, the additional irrigation requirement in 2025 will be met by (a) Inter-basin diversions, (b) Intra-basin diversions, (c) Increasing the storage capacity of existing reservoirs to capture projected increases of rainfall, (d) Increasing the irrigation efficiency and (e) Increasing crop diversification and introducing climate resilient crops.

However, the actual water supply and demand requirements will have to be analysed with a detailed river basin analysis. These studies will consider, in-basin diversions, enhancing in-basin storage, improving irrigation efficiency options and thereby optimize the infrastructure solutions and associated cost. Such studies need to be commenced immediately. Until those suggested studies are over, it is recommended to implement the proposed Strategic Action Plan to combat climate change impact in irrigation sector.

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POSSIBILITIES TO OPTIMIZE IRRIGATION IN LOWER SAXONY, GERMANY

Dominic Meinardi¹, Klaus Roettcher² and Johanna Schroeder³

ABSTRACT

The pressure on water resources is growing by the increasing demand of different users combined with uncertainties and changes in the water regime from climate change. Irrigation is of major importance for farmers in north-eastern Lower Saxony in Germany, securing the yield of potatoes and sugar beets as the main crops in this region. Different strategies to gain higher efficiency in irrigation are designed and evaluated by the operational group “sustainable irrigation” of an EIP-Agri innovation project. The establishment of a sustained network of irrigation experts is supposed to carry out activities for sustainable irrigation and water management. The foundings will take place in June 2019 at the Ostfalia University of Applied Sciences in Suderburg. Further, research on the Crop Water Stress Index (CWSI) will lead to a sensor-based irrigation management in potato fields. The Thünen Institute developed a sensor network and used field data to calculate the CWSI for using it as an indicator to determine the optimal point in time for irrigation in potatoes. Based on the founded network, first activities started with the capacity building by E-Learning courses aiming at educating students in irrigation techniques on the one hand and on the other hand providing a guidance for the Toolbox on Solar Powered Irrigation Systems (SPIS).

Keywords: Irrigation efficiency, Capacity building, Crop Water Stress Index (CWSI), Solar Powered Irrigation Systems (SPIS), Climate change, Lower Saxony, Germany

1. INTRODUCTION

The north-eastern part of Lower Saxony is the most important region for potato cultivation in Germany. It is located between the cities of Hamburg and Hannover and covers an area of about 8,400 km². The soils in this area are composed of loamy sand for the more significant part and are rather poor weak in general, however, the regional agriculture is dominated by potatoes and sugar beets. One characteristic of the light soil is a very limited water holding capacity providing good excellent conditions for the cultivation of potatoes, therefore, about 25% of all German potatoes are produced in this region. An optimal water supply is decisive for the quality and the quantity of the potato yield. The market-value of potatoes and sugar beets encouraged farmers in the past decades to implement irrigation infrastructure towards being the main irrigation region in Germany, the district of Uelzen has an irrigation infrastructure coverage over 72% in 2010 (Statistisches Landesamt Baden-Württemberg 2011). Off the record, the irrigation infrastructure coverage in 2019 is near 98% according to the chamber of agriculture in Lower Saxony and the Water and Soil Association in Uelzen.

The pressure on water resources in Germany is growing not only caused by an increased competition on the use, but also climate change plays a significant role.

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Although water consumption for agriculture is rather small in Germany compared with the international average, it sums up to about 75% in the north-eastern part of Lower Saxony. The permitted amount of irrigation water is generally calculated based on the moving average over 10 years and sums up to about 70 to 80 mm per year in the region. The contingent can be shifted within the permission period, dry years require more irrigation water, and wet years may help to save the water contingent. The water consumption must be recorded and is to be inspected once per year. Authorities are strict in punishment for exceeding the contingent water that can end up in losing the water use permission in exceptional cases. After 2018, which has been an extraordinarily dry year, the discussion starts towards exceeding the moving average to a period of 15 years for defining the amount of permitted irrigation water.

Adopting to the increasing pressure on water resources and climate change, novel concepts need to be integrated into irrigation practices for sustainable irrigation and to safeguard future yields. Different solutions can serve to reduce water consumption for agriculture. A selection of approaches is listed as follows:

- Changing to less water demanding crops
- Increasing soil quality for a better field capacity rate
- Irrigating less, accepting losses in crop quality and yield quantity
- Using more efficient technologies such as drip irrigation
- Increasing irrigation management efficiency by determining the exact irrigation time and water demand as well as inhomogeneities in the field
- Optimization of irrigation management by digitization and automatization to reduce labor costs

The Ostfalia University of Applied Sciences, jointly with the chamber of agriculture in Lower Saxony, the Thünen Institute, the University of Goettingen and a local Farmer from the district Uelzen formed an operational group named “nachhaltige Bewässerung” (sustainable irrigation) to establish an irrigation ThinkTank by identifying all relevant stakeholders and bringing them together in a sustained network. One phenomenon of temporal professional activities is the loss of established networks after the activities are completed, the aim here is to maintain the network in an association for future communications and interactions. Another goal is to develop a sensor-based irrigation support system to determine the exact water demand of potato plants based on using the Crop Water Stress Index (CWSI) as an indicator. The European Union is funding this project under the European Innovation Partnership (EIP- Agri). The project duration is from June 2016 to February 2020.

2. BACKGROUND

2.1 Irrigation Practice

Irrigation in the north-eastern part of Lower Saxony is a standard procedure by farmers of this region. One target is to not exceed the contingent water per season but, the irrigation timing is not restricted and fully entirely based on the skill set of the farmers. Irrigation practice is only briefly discussed in the curriculum of the agricultural apprenticeship. A survey within the research project gave insights on how farmers manage their irrigation. Most farmers receive the newsletter published by the professional irrigation association (Fachverband Feldberegnung e.V.) including recommendations for irrigation based on a water-balance model backed by regional meteorological data such as precipitation and evapotranspiration. Alternative methods for irrigation management are to measure the soil moisture or to observe the local weather, but mostly farmers inspect the crop and the soil in the field and finally make
a decision based on experience. However, since the fields are rather small, 10 to 20 ha on average, and spreading over a larger area, most irrigation guns are used which offer a mobile solution for irrigation. The irrigation guns need to be repositioned after irrigating one lane and need to be transported to the next field afterwards. Hence, the number of irrigation guns depends on the number of fields and the logistic capacities of the farmers for transporting and repositioning. In order to irrigate all required fields in reference to the optimal point of time, some plots will be irrigated too early and some too late. The number of stationary irrigation systems, mostly center pivot systems, is limited due to the size limitations of the fields.

2.2 Climate Conditions

With an average precipitation of about 650 to 750 mm per year, the climate is humid and moderate (DWD 2018). Climate modelling predicts a more substantial water demand for irrigation in the future, not only in the region of north-east Lower Saxony but also in areas where no demand for irrigation has occurred up to now. Heidt (2009) shows not only an extension of irrigation areas in north-east Lower Saxony but also an increasing water demand for irrigation. The pressure on the irrigation demand depends on several parameters. The critical climate parameters are precipitation, potential evaporation and temperature. The German Meteorological Service (Deutscher Wetterdienst (DWD)) released a climate report for Lower Saxony considering the RCP8.5\(^1\) scenario. Precipitation is expected to show no significant changes until 2050 but will slightly rise until the year 2100. However, the seasonal changes for this scenario predict increasing of rainfall for the winter period of about 24 % and decreasing about 12 % in the summer period.

Further, more torrential rain events will occur in the future, causing more surface runoff, which is not available for plants. The evaporation is expected to rise by about 7 % in on average until 2050 and 19 % on average until 2100. The overall positive water-balance will diminish about two-thirds until 2100. The water-balance for the summer season, however, is -69 mm and will double in the long term as an average value for Lower Saxony. The north-eastern part of Lower Saxony will suffer from the greatest more significant impact. Thus, although it is predicted that climate change cause more rainfall per year in future, increased pressure on the water resources from irrigation must be expected. (DWD 2018)

3. METHOD

3.1 Crop Water Stress Index

The Johann Heinrich von Thünen Institute is a federal research institute for rural areas, forestry and fisheries. The Thünen Institute is responsible for both, the composition of sensors for data collection and analysis and evaluation of data towards the development of the Crop Water Stress Index for potatoes. The Crop Water Stress Index is an indicator to determine the drought stress of a plant. First described in 1981 from S. B. Idso, it has been further developed by R. D. Jackson in 1981 and 1988. A crucial parameter for the CWSI determination is the difference in temperature ($\Delta T$) between the plant canopy temperature and the air temperature. A simplified equation to calculate the CWSI is as follows:

$$CWSI = \frac{\Delta T_{aktuell} - \Delta T_{optimal}}{\Delta T_{trocken} - \Delta T_{optimal}}$$

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\(^1\) Representative Concentration Pathway adopted by the IPCC for its 5th Assessment Report. RCP8.5 refers to a radiative forcing value of 8.5 W/m\(^2\) in the year 2100
In this equation $\Delta T_{aktuell}$ is the currently measured temperature difference, while $\Delta T_{optimal}$ and $\Delta T_{trocken}$ are fictive numbers describing the condition under optimal water supply (optimal) and under maximal dry stress (trocken/dry). The fictive numbers are calculated in an agricultural-meteorological model based on measured meteorological data and the Penman-Monteith equation.

The current situation and climate forecasting urge for solutions towards higher efficiency in irrigation to save water resources and adapting to climate change. The optimal water supply for the potato plant in the growth phase has a significant impact on the quality and the yield (Roth et al. 1987). Karam (2014) found out that water deficit during tuber bulking caused 12% of yield loss, but water deficit at tuber ripening led to 42% of yield loss, confirming that the timing for irrigation is crucial (Karam et al. 2014). To optimize the timing for irrigation in potatoes, the Crop Water Stress Index (CWSI) can be applied by using thermal infrared imagery. Point measures (e.g. soil moisture analysis) for determining the availability of water may only give information on spots but not on the overall plant stock in a field due to the heterogeneous conditions of the soil. (Rud et al. 2013) Discovered a high relation between the leaf stomatal conductance and the CWSI that lead to information on the in-field water availability. The thermal infrared imagery is a touchless and mobile solution to identify the CWSI and receive sound information on the plant conditions in various spots. Implementing the thermal data collection as a mobile solution allows identification of the CWSI for a whole plant stock to determine the optimal timing for irrigation. It can result in either the reduction of water use for irrigation or in an increasing quality and quantity of the potato yield.

### 3.2 Trial Fields

The Project is executed in two different sites near the Ostfalia University in Suderburg in the District of Uelzen. Both sites are composed by of the same abiotic factors such as soil type and climate conditions, but they are under different management. In total, three stations were set up to measure the plant temperature with infrared-thermometers, other sensors are installed to capture meteorological data as well. The CWSI is calculated based on the measured field data.

The trial field “Hamerstorf” is the testing field in Suderburg of the chamber of agriculture in Lower Saxony. Several experiments and trials regarding agriculture production are conducted in this site since over a decade. A part of the trial filed is used for growing potatoes in this innovation project. The potato plots are designed for a detailed assessment (Bonitur) after the seaon and switch their position each year to a place with no former potato cultivation in the last three years for phytosanitary reasons. For this purpose, different plots are set up based on the irrigation strategy for the season. The strategies are as follows:

- Reduced irrigation (usable field capacity 35%)
- CWSI 0.65 (irrigated in 2017 and 2018 according to reduced irrigation)
- Optimal irrigation (usable field capacity 50%)
- **CWSI 0.5 (irrigated in 2017 and 2018 according to optimal irrigation)**
- No irrigation

The water amount and timing for the reduced and the optimal irrigation strategy base on the measured useable field capacity. The irrigation strategy following the CWSI will take place in 2019 based on the project results of the last three years. The implementation of CWSI irrigation was planned for 2018, but an extraordinarily dry and hot season caused logistic issues that did not allow a sepearat irrigation. Each strategy is divided into four plots, of which two plots have additional potassium
fertilizer and two receive no external potassium. The whole set-up is repeated once, which sums up to 40 plots in total. Each experimental plot has two neighboured auxiliary plots for starting and stopping the irrigation machine, thus resulting in a total of 120 plots.

![Figure 1. The trial fields “Hamerstorf” in the testing area of the chamber of agriculture Lower Saxony. The plots for the irrigation trials in potatoes are the uppermost test area shown in the picture. The plots shown are from the season 2017. © 2019 Google Maps](image)

The trial field “Niendorf” is located about 12 km east of Suderburg and is a regular potato field of a local farmer. The exact location varies each year due to changing fields for potato cultivation for phytosanitary reasons. Two stations are set-up each season collecting data and verifying the CWSI calculations. Irrigation management is not influenced by the CWSI, but based on the recommendations of the irrigation association, the experience of the farmer and not least on the logistic capacities to set up the mobile irrigation infrastructure as described above. Since the CWSI in potatoes is still under development, the verification is an integrated part of the project activities. Further, mobile solutions for CWSI measurement are tested with installed infrared-thermometer on a tractor, measuring during regular work activities in the field.

### 3.3 Measurement Setup

A comprehensive collection of meteorological parameters takes place in both locations by using solar-powered monitoring stations. In the field in Hamerstorf, six infrared sensors are installed measuring different plots. These sensors with an opening angle of 35° are installed in a height of 2 m, looking southwards with a tilt angle of 60°. One sensor with an opening angle of 90° is installed in a height of 2 m, facing upwards into the sky. The two measuring stations in Niendorf have every six infrared sensors of which four have an opening angle of 35° and are installed at a height of 2 m facing i in each compass direction with a tilt angle of 60°. The other two sensors have an opening angle of 90° and facing perpendicular towards the ground and the sky at a height of 2 m. Additionally, the three measuring stations are equipped with sensors for measuring wind speed and direction, humidity, radiation, air pressure and air temperature. Moreover, one station in Niendorf is equipped with a tower measuring the wind-speed in the height of 1, 2, 5 and 10 m, with seven sensors to measure the soil heat flux as well as with an eddy-covariance system to measure evapotranspiration for verification of the calculated evapotranspiration values after Penman-Monteith.
Figure 2. The measurement set up in the trial fields "Niendorf". The picture shows the thermal sensor network installed on poles. On the left are sensors for meteorological parameter, in the middle in the foreground is the eddy covariance system. © 2017 Ostfalia

3.4 Network for Irrigation Experts

The operational group members in the EIP innovation project are the core of the irrigation network to be formed. In 2018, the Institute for Sustainable Irrigation and Water Management in Rural Areas has been established at the Ostfalia University of Applied Sciences and will serve as headquarter for the Association of Sustainable Irrigation and Water Management in Rural Areas to be founded in Suderburg in June 2019 as a first step towards the consolidation of the comprehensive irrigation network. The founding members are meant to represent the professional scope and set a target frame for future members and tasks. The association has the target of representing a broad range of interests and needs to avoid being instrumentalized by different lobby groups. Founding members cover the following professional subjects:

- Research and education (Universities, professional schools, research institutions, etc.)
- Professional organizations (Water board, Chamber of agriculture, etc.)
- Industrial/Commercial partner (Producer of irrigation technique, food processing industry, fertilizer industry, etc.)
- Authorities (District administrations, water authorities, etc.)
- Other water user such as drinking water distributors
- Organizations and administration in nature conservation
- Private persons and consultants

The focus region of the Association for Sustainable Irrigation and Water Management in Rural Areas is currently, but not exclusively, the area of north-east Lower Saxony. The regional limitation will be extended in future due to rising demand for irrigation in other regions.

4. Results and Discussion

4.1 Irrigation in Potatoes

The analysis of the irrigation trials shows clearly the impact of irrigation on the potato yield in case of a negative water balance. In 2017, there was no demand for irrigation in the region the farmer in Niendorf did not irrigate the potato fields at all. However, one irrigation took place in the testing fields in Hamerstorf. The harvest in the testing
fields in Hamerstorf show an average yield of 58.1 ton/ha for non-irrigated plots and 54.1 ton/ha in the irrigated plots. Results in 2018 clearly show the demand for irrigation under dry conditions with an average yield of 26.4 ton/ha in non-irrigated plots and 61.8 ton/ha in optimally irrigated plots. Plots under reduced irrigation had an average loss of about 5 ton/ha compared with the optimal irrigated plots.

4.2 CWSI Calculation

The measurements for the CWSI calculation took place in the growing season from April to August in 2017 and 2018. Both years, however, were not average years regarding the climate conditions. 2017 was an extraordinary wet year with about 490 mm of precipitation from April to August, and 2018 was an extraordinarily dry year with about 55 mm of precipitation in the same time frame hence the dry stress of potato plants was measured, and the CWSI has been calculated successfully. Figure 3 shows the daily curves for the CWSI, 0 means no drought stress and 1 means maximum drought stress. The water stress is growing from day to day and is reduced after irrigation on July 20th. Afterwards, the dry stress is increasing again (No data available on July 24th).

![Figure 3](image)

**Figure 3.** The graph shows the daily curves of the CWSI measured in July 2018. Cloudy and unstable conditions have impacts on the calculations. The CWSI rises from day to day and is lowered after irrigation. On July 20th was an irrigation event, on July 24th were no data collected. © 2019 Thünen Institute.

In the growth season 2019, the irrigation will follow the CWSI calculation to determine the water saving potential for this method. In future, not only the water saving potential must be considered but also the capability of increasing the yield quality and quantity by irrigating potatoes at the optimal point of time according to their growth stage. Another ultimate question could be the applicability of the CWSI method, whether to be measured stationary or mobile on a tractor or drone and the source and extend of meteorological data. The data used in the project are captured comprehensively directly from the test field, but future solutions should allow the use of regional data and require a reduced number of parameters.

4.3 Capacity Building

First activities have started by the Institute of Sustainable Irrigation and Water Management in Rural Areas at Ostfalia University in Suderburg, comprising two projects on capacity building in the field of irrigation. One project is funded by the federal Ministry of Environment for developing a blended learning E-Learning course on irrigation. The project partners are a vocational school and the chamber of agriculture Lower Saxony within the frame of the funded innovation project.

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1 Yield analysis were conducted by the chamber of agriculture Lower Saxony within the frame of the funded innovation project.
agriculture in Lower Saxony. The E-Learning course is adaptive to focus either on training vocational agricultural apprentices or university students. The other project is a cooperation between the Ostfalia University in Suderburg with the German Society for International Cooperation (Deutsche Gesellschaft für International Zusammenarbeit (GIZ) GmbH) to promote a Solar Powered Irrigation Systems (SPIS) toolbox, which is a comprehensive program providing a broad hands-on guidance to end users, policymakers and financiers on SPIS. A multilingual E-Learning course is to be developed for facilitating the application of the toolbox and raise awareness of technical solutions and financing schemes with a focus on developing Countries.

The positive response and the vast interest into the association for sustainable irrigation proofed that the concept of establishing a sustained network was the right step. The growing pressure on water resources will create questions in future that can be addressed now to an active network of experts.

5. CONCLUSION

The demand for irrigation will rise in future. Not only in arid and semi-arid regions of the world but also countries with a moderate climate and a positive water balance. As shown, the annual precipitation is no unique indicator; many factors such as the timely distribution of rain, soil conditions and uncertainties from climate change play a significant role. A successful adaption strategy to the climate change and future irrigation demand starts on several levels, technical solutions for higher efficiency in irrigation are such as necessary as a functional network of experts pursuing solutions and a sufficient knowledge basis for the farmer, operational staff and planners.

The CWSI has a great potential to manage irrigation with increased efficiency, and the first results show the general functionality of the concept. Further studies must consider the applicability for farmers and need to focus on simplification and a mobile solution for CWSI determination. A major issue for higher efficiency in the study region is the use of irrigation guns, more energy and water saving solutions are available and their implementation should be encouraged with greater insistence.

The sustained network of irrigation experts and stakeholders is another step towards higher efficiency in irrigation. It will lead to progress in communication and foster new approaches and concepts. The continuation of tasks and the permanent presence will have effects on the public and local/regional authorities keeping the subject of irrigation present and underscores the importance of solutions required. The capacity building projects of the Institute for sustainable irrigation are only the beginning of educational activities. The demand for research and education is high, thus further activities are currently reviewed such as an international training center for irrigation, and water management in rural areas.

Another promising approach is solar powered irrigation systems which contain the significant potential to change the future of irrigation on a large scale. Not only the independence from power grids and fossil fuels offer a chance to cultivate new areas, the modern technology also takes the next step towards smart farming. Water use monitoring is a built-in option, offering analysis opportunities for constant improvement in efficiency.

6. REFERENCES


DETERMINING IRRIGATION AND DRAINAGE RATES TO ANTICIPATE EXTREME WEATHERS

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ABSTRACT

To achieve sustainable farming in the context of climate change and facing extreme weather requires sound information on the climate trend, weather pattern and rainwater availability. Objectives of this study were to identify how climate change has occurred locally, to calculate the rainwater deficit/surplus during extreme dry/wet weather, and to determine rates of irrigation/drainage required to anticipate drought/flooding. Study location was in Serang Regency, Banten Province, Indonesia. Climate data obtained from 1978 to 2018 consisted of daily minimum temperature, maximum temperature, averaged temperature, relative humidity and rainfall. Daily evapotranspiration was calculated with Hargreaves’ model. Available rainwater was calculated as rainfall minus evapotranspiration. Climate change was analyzed by a linear model and its significance was determined by the Mann-Kendall method. Since El Niño in 1997, the study location has experienced climate change indicated by the increase of air temperature (+0.05 °C/y) and decrease of the annual rainfall (-0.12 mm/y). Extreme dry and wet periods occurred in 1997, and 2013 when the annual rainfall amounted to 1115 mm and 2914 mm, respectively. The dry season in 1997 OR 2013 started from end-April to mid-September followed with wet season until mid-April and a transition period from mid-April to end-April. Peak of the wet season and dry season was in the first week of January and the third week of July, respectively. On average, rainfall was 231mm more than the evaporative demand. During the dry season, rainwater was normally in a deficit of 2.5 mm/d but during some extreme events the deficit was 3.8 mm/d. In the wet season, rainfall was normally higher than evaporative demand by 2.8 mm/d, but under extreme events, the surplus was 10 mm/d. In the extreme weather events, the required irrigation and drainage rates per one hectare are -1.56 m³/h and 4.15 m³/h, respectively.

Keywords: Climate change, extreme weather, available rainwater, irrigation, drainage.

1. INTRODUCTION

Climate change indicated by the rise of average air temperature has been a focus of global attention [1]. Climate change has caused frequent extreme dry/wet weather events often followed by longer drought/flooding [2]. Many efforts have been made to prevent the temperature rise not to exceed 2 °C from the pre-industrial era [3]. Shifts in the growing season due to climate change is another problem that is troubling farmers who need to determine the right time to start cultivation [4]. Irrigation planners must reformulate water demand subjected to the uncertainty of climate [5].

Many techniques are available to manage the water in paddy fields. Among others are alternate wetting and drying [6], shallow/no water ponding [7] and subsurface drainage [8] that have proved capable of increasing land / water productivities and decreasing greenhouse emission.

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A remaining task, however, is how to prepare proper irrigation/drainage infrastructure capable of facilitating water management effectively. This task needs information on adequate irrigation/drainage rates required during extreme dry/wet periods. It is then important to know when dry/wet periods occurred in the long-term dataset to identify extreme dry/wet periods including calculating the status of rainwater whether giving a deficit or a surplus.

It is also essential to use a deterministic method to identify dry/wet periods with the details of its Start, End, Length, and Peak. Here, we introduced a polynomial equation to interpolate each accumulated rainfall and evapotranspiration, and further, determined the rates of rainwater deficit/surplus at the extreme dry/wet period.

The objectives of this study were to make sure how climate change occurred locally, to figure out the rainwater deficit/surplus during extreme dry/wet weather, and to determine the rates of irrigation/drainage required to anticipate drought/flooding.

2. METHODOLOGY

The studied location was in Serang Regency, Banten Province, Indonesia (Error! Reference source not found.). Climate data were obtained from the Meteorology Station managed by the National Agency of Meteorology, Climatology, and Geophysics (BMKG). This station is registered with World Meteorological Organization (WMO) code of WMO-96737 and is located at geographical coordinate S:6.11185°, E: 106.11° at an altitude of 100 m above sea level.

![Figure 1. The study location in Serang Regency, Banten Province, Indonesia](image_url)

The meteorological station has been active since 1978 measuring hourly temperature, relative humidity, wind speed and direction, barometric pressure, sunshine duration, and daily rainfall. In general, the recorded data is of a good quality, but there are some quantifiable missing data of the sunshine duration and the wind. For example, in 2001, more than 33% of the data is missing data. Due to these constraints, the climate data used for this study comprised: 1) Daily Minimum (Tmn), Maximum (Tmx) and Average Temperature (Tav), 2) Daily Average Relative Humidity (RH) and 3) Daily Rainfall (R), were obtained via [http://dataonline.bmkg.go.id/home](http://dataonline.bmkg.go.id/home) from 1978 to 2018 (41 years). Evapotranspiration (ET) was calculated using Hargreaves’ model [9] as follows:
\[ ET = Co \sqrt{T_{mx} - T_{mn}}(T_{av} + 17.8) \ast Ra \] (1)

where the constant Co=0.000939 and Ra is the extra-terrestrial solar radiation which was estimated based on the geographical position and Julian day [10].

Parametric linear equation and non-parametric Mann-Kendall method [11] [12] (Eq. 2 – Eq 5)\(^3\) were used to identify the change of every climate component. The slope of the linear equation was used to determine the trend of the change whether it was positive or negative. The score of Mann-Kendall was used to determine the significance of the change subjected to a significant level of 95%.

\[
Z = \begin{cases} 
(S - 1)/\sigma_S & \text{if } S > 0 \\
0 & \text{if } S = 0 \\
(S + 1)/\sigma_S & \text{if } S < 0 
\end{cases} \tag{2}
\]

\[ f(Z) = \frac{1}{\sqrt{2\pi}}exp(Z^2) \] (3)

\[ S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sign}(x_j - x_k) \] (4)

\[ \sigma_S = \sqrt{n(n-1)(2n+5)/18} \] (5)

where \( Z \) is the score of Mann-Kendall and \( x \) is a climate component to be evaluated.

To determine dry and wet Periods, a polynomial equation was used to interpolate the accumulation of daily rainfall and evapotranspiration every year [12]\(^3\). Dry/Wet Period was determined when the amount of daily rainfall was smaller/larger than the daily evapotranspiration. A Dry/Wet Period was identified to occur when the difference between the daily rainfall and evapotranspiration was negative/positive. This rate was the first derivate of the polynomial equation. Later, each Dry/Wet Period was combined to determine Dry/Wet Season. Is it per year? Or mean over period?

Required irrigation/drainage rate to anticipate extreme dry/wet weather was determined based on the highest rate of the rainfall deficit/surplus. The extreme Dry/Wet Weather was determined based on the smallest/largest rainfall and the longest/shortest dry season in the period of 1978–2018.

3. RESULTS AND DISCUSSION

3.1. Climate Zone

Add a summary sentence sort of the main finding in this paragraph before starting with the figure.

![Error! Reference source not found.](image-url) shows monthly rainfall (R) and evapotranspiration (ET) which were averaged over 40 years. Dry months occurs from July to September with the 3-month total rainfall 304 mm while wet months occurs from October to April with the mean 7-month total rainfall received 2284 mm with March as the peak of the rainy days (not shown). The ratio of dry months to the wet months was 13.3% in which according to Schmidt-Fergusson, this location is classified as A-Type or climatically wet region [13] and according to Oldeman, the location is classified as C-Zone having a consecutive 7 wet months with the mean monthly rainfall ≥ 200 mm [14].

\(^3\) Programmed in Visual Basic Editor in MS Excel free for those who interested to use or develop.
Figure 2. Monthly Rainfall (R), Evapotranspiration (ET) and RED not defined? (in mm per month) calculated from 1992 until 2017. For “give name of the place” using BMKG climate data.

Under these climate conditions, the location is desirable for paddy cultivation with at least two planting seasons or 200% planting intensity. The first planting season is approximately from October to January and the second planting season from March to June. A third planting season is possible from July to September specifically to grow drought-resistant upland crops such as corn and soybean with irrigation. Irrigation water is also essential for the second planting season when there are 2 consecutive dry days. Irrigation structures have been built in Serang regency covering 88,000 ha of paddy fields [15] for an average of 2 plantings per year.

3.2. Climate Change

ADD sentence Figure 2 shows the daily average temperature (Tav) and the annual rainfall (R) over the period of 1978–2018.

In the overall, Tav ranged at 26.7±0.37 °C and tended to increase with the slope of +0.0197 °C per year. Tav increased from 26.3 °C to 27.1 °C (+0.79 °C) over the 40 y. Before El Niño in 1997, the slope of Tav was -0.02 °C per year (not shown). After that, the slope was +0.05 °C per year indicating that El Niño has given its effect on the temperature rise. Mann-Kendall confirmed that the increase in temperature was significantly positive.

There were 7 years (1986, 1993, 1994, 1995, 1996, 1999 and 2001) in which Tav was lower beyond the range with the lowest Tav being 26.2 °C in 1994. While, there were 5 years (2014, 2015, 2016, 2017 and 2018) in which Tav was higher than what? with the highest Tav was 27.6 °C in 2016.

From 1978 to 2018, R ranged within 1677±369 mm with slope -5.443 mm per year with the lowest being 1115 mm in 1997, and the highest 2914 mm in 2013. Before 1997? El Niño, there were 1 lower and 4 higher R beyond the range with the slope 8.18 mm per year (not shown).

After that, there were 6 lower and 2 higher R beyond the range with the slope of -0.12 mm per year (not shown). Mann-Kendall confirmed that R decreased significantly with time from 1978 till 2018.
For other climate components, the daily Relative Humidity (RH) and the annual potential Evapotranspiration (ET) ranged at 81±1.42 % and 1616±66.15 mm respectively. Neither changed significantly with time. While the available rainwater (ARW) ranged from -527 mm in 1982 to 1342 mm in 2013 and decreased with time at the rate of 4 mm/y (Shown where?).

In conclusion, this location has experienced local climate change as indicated by the increase of the daily air temperature, and the decrease of the annually available rainwater (not shown). The change was steeper after El Niño in 1997 (not shown).

3.3. Dry and Wet Seasons

Add sentence here Figure 3 shows the process to identify wet and dry periods for two cases, in the year 1997 and 2013, which were identified as the driest period and the wettest period.

Two curves from the top display the daily and accumulated data of rainfall (R) and evapotranspiration (ET). Lines represent 6th order polynomial equations interpolating the accumulated data. The equations were accurate for all cases from 1978 to 2018 resulted in the coefficient of determination ($R^2$) in the range of 0.989 to 0.998.

Fig. 4(c) or whatever show two lines representing the first derivatives of the equations, each as the rate of R and ET. Dry Period is a period when the R is smaller than the ET. While Wet Period is a period when the daily R is larger than the daily ET.

Fig. 4(d) shows a line representing the difference between the R and that of ET (R-ET). Herewith, Dry Period is the period when the difference is negative, and the Wet Period is the period when the difference is positive. In 1997, the Dry Period started from 131st day then passed to the next year (1978) with the lowest value occurring on julina day 240. While in 2013 the Dry Period started from 211st to 264th day with the lowest value on 240 day. The end of the Dry Period means the Start of the Wet Period. Accordingly, End of the Wet Period means the Start of the Dry Period.
Figure 3. Wet and Dry Periods in the Years of 1997 and 2013 ADD MUCH more DETAILS which graph a=? b=? c=? & d=? check labels ? is rain in mm/d?

Table 1 shows Start, End, Length, Water Depth, Peak Day and Peak Rate of the Wet Period and Dry Period averaged from 1978 to 2018. In general, there were 3 Wet Periods and 3 Dry Periods (Figure 4) occurred in the following sequences.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Wet1</th>
<th>Dry1</th>
<th>Wet2</th>
<th>Dry2</th>
<th>Wet3</th>
<th>Dry3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occurrence in 40 years</td>
<td>12%</td>
<td>2%</td>
<td>15%</td>
<td>68%</td>
<td>83%</td>
<td>90%</td>
</tr>
<tr>
<td>Start (day)</td>
<td>1</td>
<td>107</td>
<td>266</td>
<td>327</td>
<td>330</td>
<td>358</td>
</tr>
<tr>
<td>End (day)</td>
<td>121</td>
<td>265</td>
<td>326</td>
<td>329</td>
<td>351</td>
<td>365</td>
</tr>
<tr>
<td>Length (days)</td>
<td>121</td>
<td>158</td>
<td>62</td>
<td>3</td>
<td>22</td>
<td>8</td>
</tr>
<tr>
<td>Length (% in 365 days)</td>
<td>33%</td>
<td>43%</td>
<td>17%</td>
<td>1%</td>
<td>6%</td>
<td>2%</td>
</tr>
<tr>
<td>Av. Rainwater (mm)</td>
<td>398</td>
<td>-354</td>
<td>205</td>
<td>-139</td>
<td>146</td>
<td>-25</td>
</tr>
<tr>
<td>PeakDay (day)</td>
<td>8</td>
<td>200</td>
<td>301</td>
<td>301</td>
<td>348</td>
<td>264</td>
</tr>
<tr>
<td>PeakRate (mm/day)</td>
<td>10.0</td>
<td>-3.8</td>
<td>5.4</td>
<td>-1.9</td>
<td>6.1</td>
<td>-1.5</td>
</tr>
</tbody>
</table>

123\textsuperscript{rd} day can be considered as the transition period from Wet1 to Dry1. until 351\textsuperscript{st} and followed Dry3 until 365\textsuperscript{th} day. The overlapping days from 109\textsuperscript{th} day to followed by Wet2 until 326\textsuperscript{th} day, followed by Dry2 until 329\textsuperscript{th} day, followed by Wet3 Wet1) started from 1\textsuperscript{st} day to 123\textsuperscript{rd} day, followed by Dry Period (Dry1) until 262\textsuperscript{nd} day, Periods and 3 Dry Periods (Figure 4) occurred in the following sequences.

Wet Period Considering the occurrences and the length of each period, as shown in Figure 4, it can be determined that the Dry Season may be from 107\textsuperscript{th} day in April to 265\textsuperscript{th} day in September, and the Wet Season may start from 266\textsuperscript{rd} day in September to 106\textsuperscript{th} day in April, and the transition period from the Wet Season to the Dry Season starts from 105\textsuperscript{th} day to 122\textsuperscript{nd} day. Furthermore, the Peaks of the Wet Season and Dry Season are on the 8\textsuperscript{th} day and 200\textsuperscript{th} day, respectively.
Figure 4 Wet and Dry Seasons

3.4. Irrigation and Drainage Rates

Table 1 shows also Available Rainwater (ARW) which is the net of the daily amounts of R and ET (R-ET), the peak day of each period (Peak Day) and the rate of ARW (Peak Rate) at the Peak Day. Positive ARW means daily rainwater surplus while Negative ARW means daily rainwater deficit.

The largest surplus was 398 mm in Wet1 with the Peak Rate 10 mm/d on the 8th day, and the largest deficit was 354 mm in Dry1 with the Peak Rate -3.8 mm/d on the 200th day. In the overall, ARW was surplus amounted to 231 mm. This amount, if it can be conserved, is substantial to reduce the rainwater deficit in the Dry Season.

In a normal Dry Season, the average ARW was -2.5 mm/d or about -1.03 m$^3$/h in one hectare. While, in the extreme Dry Season, the largest AWR was -1.56 m$^3$/h in one hectare. The largest AWR can be used to determine the required Irrigation Rate to anticipate the extreme Dry Season.

In a normal Wet Season, the average ARW was 2.8 mm/d or about 1.18 m$^3$/h over one hectare. While, in the extreme Wet Season, the largest AWR was 4.15 m$^3$/h over one hectare. The largest AWR can be used to determine the required Drainage Rate to anticipate the extreme Wet Season.

As flooding is the common threat during the Wet Season, drainage infrastructure capable to prevent it is indispensable. The drainage facility should be capable to drain out the surplus rainwater at 4.15 m$^3$/h per hectare.

The drained water is better relocated to artificial water storages to anticipate water deficit in the Dry Season. Long water storage structure can be a type of water canal constructed parallel along a contour line that receives surface run-off. With a canal depth of 2.5 m and width of 5 m, the capacity of long water storage is about 10 m$^3$ per m-length.

The canal will have other functionalities such as to reduce flooding, to provide additional irrigation water, for fishery and water source for the water treatment plant. As an example, a 9-km long water storage, located the coordinate of (6°32'59.60"S,108°29'40.37"E–6°37'47.68"S,108°30'41.52"E) in Indramayu regency of West Java Province, is vital to prevent flooding and release the effect of drought and intensify paddy cultivation up to three times.
4. CONCLUSIONS

The study location according to Schmidt-Fergusson belongs to A-Type what? and according to Oldeman belongs to C-Zone what? Climate zone? Agroecozone? which is desirable for paddy cultivation with two-time planting intensity every year.

Since El Niño in 1997, the studied location has experienced a steeper climate change indicated by the increase of air temperature (+0.05 °C/y) and decrease of the annual rainfall (-0.12 mm/y). not shown.

Extremely dry and wet weather occurred in 1997 and 2013 when the annual rainfalls amounted to 1115 mm and 2914 mm, respectively.

The dry season starts from end-April to mid-September followed with wet season until mid-April and a transition period from mid-April to end-April.

Peaks of the wet season and dry season were on the first week of January and the third week of July, respectively. Not convincing evidence.

In the mean, rainfall able to be stored has an annually surplus of 231 mm.

In the dry season, rainwater was normally in deficit by 2.5 mm/d but in extreme situation, the deficit was 3.8 mm/d.

In the wet season, rainwater was normally in surplus by 2.8 mm/d but in the extreme case the surplus was 10 mm/d.

In the extreme weather, the required irrigation and drainage rates for one hectare are 1.56 m³/h and 4.15 m³/h, respectively.

5. REFERENCES


[13] F. Schmidt and J. Fergusson, 1951 Rainfall types based on wet and dry period ratios for Indonesia with Western New Guinea, Jakarta: Djawatan Meteorologi dan Geofisik, #pg?


VALUE ADDED WEATHER ADVISORIES FOR SMALL-SCALE FARMERS IN SOUTH AFRICA DELIVERED VIA MOBILE APPS

Sue Walker

ABSTRACT

Maize is the staple crop for most of southern Africa. However, it is dependent on the high variability of summer rainfall, in particular, the start of the rainy season, which affects planting dates, especially in semi-arid areas. Therefore, every growing season, farmers make a decision about when to plant their crops. Agrometeorologists have climate and weather information available to assist such decisions and have engaged farmers and other stakeholders to find the gaps in the flow of production relevant information. There are practical applications of modern electronic communication technologies to distribute real-time information pertinent to the farmers’ current situation. The Rain for Africa (R4A) consortium, including South Africa and Netherlands partners funded by the Netherlands Space Office, has developed a mobile phone app, AgriCloud. It gives updated information on a daily basis to both extension practitioners and small-scale farmers. The AgriCloud advisories are for a specific location in a selected local language on android phone or via a USSD updated every day. This App has enabled the farmers to use the rainwater available in a more sustainable way. They were able to plan their land preparation and planting activities a week before according to the weather forecast for their own farm. The advantages are that they can obtain a daily update with farming relevant advice, in their own local language on their own phone in their hand. Farmers and extension practitioners are eager to receive daily updates on a regular basis with agricultural information that is applicable to their own farming conditions. Unique aspects of AgriCloud are that it includes a crowd-sourcing collection of qualitative weather observations from the farmers and extension practitioners. Mobile Apps are useful to integrate information about maize crops with current short-term forecasts to give planting date recommendations to farmers for their specific farm location.

Keywords: climate services, planting advice, mobile App, South Africa,

1. INTRODUCTION

Most of agricultural production in South Africa is under rain-fed conditions in the semi-arid climate at a high altitude. This means that the crops often suffer water deficit and water stress due to insufficient rainfall during the growing season. It has long been know that key gaps exist in technology transfer, including the lack of climate outlook information and a lack of translation and interpretation in terms of language and terminology used in advisories (Archer et al. 2007). One of the main limitations to maize production is using suitable planting dates due to low availability of accessible and accurate climate forecasts (Fisher et al. 2015).

As the staple food in southern Africa is maize porridge eaten at least twice per day, the farmers need to cultivate large areas of maize crops often in rain-fed marginal areas (Fisher et al. 2015). The maize is cultivated during the summer rainfall season when there is no danger of frost. However, as it is a semi-arid area, the rainfall is highly variable, in both amount and starting date. Therefore, farmers can make plans for the planting season, but usually have to wait until sufficient rainfall is received before they can plant the maize seeds (Makuvaro et al. 2017).

1 Agricultural Research Council – Soil, Climate & Water, Pretoria; and Dept. Soil, Crop & Climate Sciences, University of Free State, Bloemfontein, South Africa
From drought analysis, using daily rainfall it is apparent that the timing of the start and end of the rains is most important. However, as analyses show trends for seasons to start later (Taros et al. 2009), although other studies do not all agree (Stern & Cooper 2011). As extended dry spells are common during the summer rainfall season in Southern Africa, they have devastating effects on maize agricultural production. This is especially true if they occur during sensitive stages of crop growth such as germination, flowering, and grain-filling of maize. Therefore, it of paramount importance to assist farmers with agricultural information based on weather forecasts especially for planting decisions.

Therefore, it is vital that farmers have good local weather forecast to assist them in their planning and on-farm decision-making. At present, publically available weather forecasts only give the expected weather conditions for the next 2 to 3 days for the main centres. Therefore, a farmer situated a long distance from these centres cannot easily obtain accurate weather forecast for the next 10 to 14 days (medium-term forecasts). Another aspect of the farmers' decision-making is about knowing which decisions they make on a regular basis are dependent on which weather parameters. Thus when these relationships between the climate parameters and on-farm operations are known, then it is possible to add value to the weather forecast in the form of agricultural relevant information about farming activities. Such Agromet advisories are then derived from the weather forecast according to the specific farming systems and locality to be provided to the farmers.

2. METHODS

Meetings were held with both small-scale farmers and extension practitioners to assess needs of the farmers concerning weather information for farming practices. This information was used to direct the development of Agromet advisories following an action research methodology. Following an assessment of the currently available weather forecasts and daily weather data, it was decided to proceed with development of planting advisories as well as advice for conditions for spraying of pests and diseases.

The medium-term weather forecast was obtained from the European Centre for Medium-range Weather Forecast (ECMWF) (https://www.ecmwf.int/en/forecasts) via the South African Weather Service (www.weathersa.co.za) and HydroNet (https://www.hydronet.co.za/). This included the daily forecast weather parameters (maximum and minimum air temperature, rainfall amounts, wind etc) for the upcoming 14 days on a grid (15km) across the whole of South Africa.

The main maize growing regions of South Africa were delineated on the map. The long-term start and end dates for frost (0°C) were calculated for a grid across South Africa. The operation of the knowledge engines (with agricultural criteria) were programmed in Python script, so as to access the information from the rainfall stations, weather forecasts and generate an output for each of the grid cells across South Africa for each day. This information is then transferred to the HydroNet platform to be distributed to the AgriCloud mobile App (downloadable free from Google Play Store).

3. RESULTS AND DISCUSSION

3.1 Development Process

In such a trans-disciplinary type of project there are many players who need to be drawn together to each make their contribution to be able to implement the end to end
service from scientific data through to farmers. The process can be initiated either from a top-down approach or bottom-up approach or preferably from both sides simultaneously.

3.2 Farmers’ Requests

The farmers’ needs were identified during 2017 using a one-on-one questionnaire during Agromet information meetings held across several provinces in South Africa. Some of the main finding pertinent to this paper was that about a third of the rural small-scale farmers had access to an android smartphone and mostly they obtain weather information from radio or TV broadcasts (Phahlane et al. 2019). The farmers highlighted the fact that the currently available weather forecasts are not for their own locality, but usually focus on the main cities across the country. They however know that the weather conditions, particularly the rainfall, on their own farms are often different from those reported. Therefore, they request more detailed weather forecast information for their own location. They also underlined the fact that they wanted to learn more about how to use such weather forecast information in their farming decisions.

3.3 Climate Sensitive Farm Decisions

It is this information that then drove the researchers to investigate the climate sensitive decision in the maize production farming systems used by dryland farmers in semi-arid areas in South Africa. This led them to identify a few multifaceted process within the normal routine cropping programme that are sensitive to the variable climatic conditions. However, it is not only that there are critical stages during the growth cycle of the maize crop which are affected adversely by the weather conditions, but also that there needs to be an intervention that can be taken by such a farmer. Merely to know that a certain process in the growth of a crop is influenced by a weather parameter is not helpful. There also needs to be some action that a farmer can take to change the adverse effect of those weather parameters. Therefore, these criteria are developed from the historic climate data and a range of agricultural scientific studies with detailed information.

3.4 Knowledge Engines

All the data sources and links need to be identified and then access needs to be negotiated with the owners of the data or the partners who will contribute the relevant information. These steps can be time consuming and laborious as much specific detail needs to be clarified and use agreements negotiated once the required information source has been located. The specific agricultural information is formulated into Knowledge Engines that contain the specific algorithms that relate the farming decisions to the weather parameters. In an operation mode these are then run on a daily basis to generate advisories from the current weather forecast information. They are calculated on a grid across the country, so that the advisories can be accessed on a 15km grid bases for each of the registered farmers.

3.5 Rollout and use of AgriCloud

The AgriCloud Mobile App went live in September 2018 in South Africa after a beta test phase since May 2019 (Fig. 1). The main rollout was to extension practitioners and farmers across the eastern summer rainfall part of the country via a number of workshops and training sessions. There was a steep uptake monitored by the number of downloads from the Google Play Store (Fig. 1), notably in September, then again during the first half of the summer rainy season when the rains were expected.
Figure 1. Google analytics showing the increase in number of users from the beta test version in May 2019, until the roll-out in September 2019, and then through the first half of the summer. The number of users and sessions, as well as the length of the sessions is also given.

The success of the AgriCloud App is closely monitored. The number of return users is above 70%, which shows that once they have downloaded the AgriCloud App, they return to check the planting information again later (Fig. 2).

Figure 2. The comparison of users shows a high number returning (71%) for the updates about the best planting time.

As was expected, the younger farmers and extension workers are the main users, with most being under 44 years old (Fig. 3). There has been an equal spread of both males (54%) and females (45%) using AgriCloud (Fig. 4).

3.6 Unique Aspects of AgriCloud

Some of the success of the AgriCloud mobile App is attributed to the specific unique aspects that are included in the App. This was due to the good testing of the market prior to the design and development of the App. Firstly, the AgriCloud advisories are available for a specific location that is selected when one registers a farmer on the
App. This registration is done using a Google type map where one can pinpoint the exact location of your farm.

![Age Distribution](image)

**Figure 3.** Showing that more than 60% of the users are between 18 and 34 years old.

![Gender Distribution](image)

**Figure 4.** Almost equal numbers of male and females have downloaded the AgriCloud App.

This is an important feature as the farmers had noted that the generally available weather forecast are usually for the main towns or cities and have little relevance for their farm locations. Secondly, the advisories are available in all 11 South African official local languages. This has proved to be a distinct advantage to promote the use of the AgriCloud App in the rural areas amongst the semi-literate older community of small-scale farmers. During the registration of the farmer on the App, one can also select a preferred language and then all the information provided will appear in that language. So, even if the user speaks a different language, they can set the language to the farmers mother tongue and then more easily provide the advisories to them. A third advantage of the AgriCloud App is the fact that the information is updated on a daily basis, even though the forecast advisory is given for each day in the up-coming 10 to 14 days.

This enables the farmers to make plans for their field operations more than a week in advance, and then check back closer to the time for an updated forecast advisory. For example, they can plan their land tillage preparations and planting activities a week before according to the weather forecast for their own farm.
3.7 Crowdsourcing

Other aspects about the AgriCloud App are that a crowdsourcing mode is build-in for the farmers and extension officers to provide feedback on the current weather conditions at their own farm such as wind or rain or sunshine (Fig. 5). At present, this is in the form of a selection of a simple pictorial record, and focusing on weather hazards like thunderstorms, tornados, mist, frost, hail or flooding conditions (Fig. 5). This collection of extreme weather conditions will be made available to the weather forecasting office to check the accuracy of their forecasts.

![Figure 5. Screenshot of the crowd-sourcing part of AgriCloud where the farmer can record the occurrence of rain or hail or frost or flooding etc.](image)

3.8 AgriCloud Products

Another advantage is that the AgriCloud system was designed and developed in a modular system making it easier to add new advisories in future. Since the mobile App was developed, the R4A team has also developed a number of other agricultural advisories based on weather and climate information for different crops and livestock systems around South Africa. AgriCloud is also available in two other formats namely on a web platform portal or dashboard and on a direct customised service via an API (Application Programming Interface) directly to the customer’s computer. This means a specifically designed set of reports including graphs and tables can be developed for a particular client - including a set of functions, communication protocols, and tools creating application outputs relevant to their own business objectives. Such services and access to the portal or dashboards will be marketed on a commercial basis to a range of agri-business and commodities users.

4. CONCLUSIONS

Information needed by farmers is added to the current weather forecasts on a routine basis to create agro-climate or Agromet advisories that address the specific farming systems in their own location. Such Agromet advisories are delivered by mobile app to supply farming relevant advice, in a local language on their phone in their hand and updated on a daily basis. These mobile Apps integrate information about cropping and livestock systems with current short-term and medium-term weather forecasts to
give advice on decisions about planting and spraying to farmers for their specific farm location for the upcoming 2 weeks.

5. ACKNOWLEDGEMENTS

This work formed part of the Rain for Africa (R4A) project funded by the Netherlands Space Office (NSO) as a Geodata for Agriculture and Water (G4AW) with the following partners – South African Weather Service, HydroLogic, and Weather Impact. Thanks are expressed to all team members, farmers, and extension practitioners who contributed to the success of the R4A project and development of the AgriCloud App. Attendance at the ICID conference is funded through the University of the Free State, Bloemfontein, South Africa.

6. REFERENCES


